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**Modeling of Stationary Air Pollution Sources in the
Central and Western Kern County Oil Fields
Task Report. Volume I: Text**

SRI International, Menlo Park, CA

Prepared for

Environmental Protection Agency, Washington, DC

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MODELING OF STATIONARY AIR POLLUTION SOURCES IN THE CENTRAL AND WESTERN KERN COUNTY OIL FIELDS

Task Report — Volume I: Text

January 1979

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Contract No. 68-01-4137

SRI Project 5828, Task 7

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ABSTRACT

The use of steam injection to recover the high viscosity oil in Kern County, California has created the potential for violation of federal and state ambient air quality standards in that area. The increasing number of permit applications for development of new steam generation facilities has prompted the Environmental Protection Agency to commission a study to determine the sulfur dioxide levels produced by the present and proposed configurations of crude oil-fired steam generators. This report presents the results of that study.

Two locations in Kern County were of interest: the oil fields in the central portion of the county, near Bakersfield, and the fields well to the west of Bakersfield, lying on a roughly NW to SE line about 40 miles in length, between the towns of McKittrick and Maricopa.

To assess the air quality at the two locations, data describing the meteorological conditions, the measured SO₂ levels, and inventories of both generator and nongenerator sources were collected and reduced. A limited verification of data detailing generator source characteristics, particularly location, was performed.

The Climatological Dispersion Model (CDM) was modified and used to compute annual average SO₂ concentrations in both central and western Kern County. These concentrations were then calibrated using observed SO₂ data. In central Kern County model predictions for the existing source configuration showed a violation of the federal annual SO₂ standard. For the future source configuration the possibility of a violation was predicted. No violation of the annual standard was predicted for either the existing or future source configuration in western Kern County.

A slightly modified version of the CDM was used to compute worst-case 1-hour, 3-hour, and 24-hour average SO₂ concentrations in central

and western Kern County. Concentrations arising from both the existing and future source configurations were computed. No violation of the federal short-term average SO₂ standards was predicted.

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I INTRODUCTION

Reclamation of the high viscosity oil in the central and western Kern County, California fields requires the application of thermal recovery methods. In Kern County thermal recovery is accomplished by the injection of steam into the oil reservoir at numerous points. The steam reduces the viscosity of the oil and increases reservoir pressure, so the oil can be pumped to the surface. Steam is produced by a number of generators located in the oil fields and fired by crude oil.

An increasing number of permit applications for development of new steam generation projects in the central and western Kern County oil fields have been submitted to EPA pursuant to the New Source Review regulations (40 CFR 52.233 (g)). In most cases the steam generators are to be fired with crude oil having on the average a sulfur content of 1.1 percent. The large SO₂ emissions associated with these generators have caused concern over attainment and maintenance of SO₂ levels in accordance with the national ambient air quality standards. Several applicants have contracted with consulting firms for air quality modeling studies of the affected areas to determine the effects of present and future emissions on the local air quality. EPA is responsible for determining whether the proposed projects will interfere with attainment or maintenance of air quality standards. Thus, it is necessary for EPA to evaluate the accuracy and adequacy of the modeling and computations performed by the oil company consultants, and to determine the amount of emissions reduction needed to avoid violation of the air quality standards.

This report documents SRI International's evaluation of air quality in the central and western Kern County oil fields. The ambient air quality standards for SO₂, applicable to the oil fields, are discussed in Section II, and the air quality simulation model used in this study, CDM, is described in Section III. In Section IV we discuss the modeled

region, and the required model input data describing the sources, meteorology, and air quality. The generator source verification and air quality siting analysis are also presented in this section. The results of the modeling of long-term average concentrations appear in Section V, and the results of the short-term modeling are given in Section VI. Volume II, which accompanies this report, consists of two types of appendices: appendices A-L contain data used as model input, and appendix M details modifications made to the original CDM source code.

II AIR QUALITY STANDARDS

The air quality standards for SO₂ to which the steam generators are subject are: (1) the federal primary annual and 24-hour standards, (2) the federal secondary 3-hour standard, and (3) the State of California 24-hour and 1-hour standards. The federal and State of California SO₂ standards appear in Table 1. It is against these standards that the results of the modeling effort have been compared.

Table 1

FEDERAL AND CALIFORNIA AMBIENT SO₂ STANDARDS

Type of Standard	Averaging Time	Standard (µg/m ³)	Standard (ppb)**
Federal primary	1 year	80	30
Federal primary	24 hours	365*	139*
Federal secondary	3 hours	1300*	496*
State of California	24 hours	131 [†]	50 [†]
State of California	1 hour	1310	500

* National primary standards: The levels of air quality necessary, with an adequate margin of safety, to protect the public health. Each State must attain the primary SO₂ standards no later than 1982.

National secondary standards: The levels of air quality necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant. National standards, other than those based on annual averages or annual geometric means, are not to be exceeded more than once per year.

** Units of parts per billion (ppb) are based on a reference temperature of 25°C and pressure of 760 mm of mercury.

[†] With simultaneous violation of State 1-hour oxidant standard or State 24-hour suspended particulate matter standard.

III CLIMATOLOGICAL DISPERSION MODEL

The air quality dispersion model used in this study to predict the SO₂ concentrations resulting from the steam generators in the central and western Kern County oil fields is the Climatological Dispersion Model¹ (CDM). The CDM was modified slightly and used to compute annual average and short-term average concentrations. A general description of the CDM and a discussion of the modifications made to the model are given below.

The computerized CDM makes it possible to calculate long-period seasonal or the annual average pollutant concentration patterns that result from stationary point sources and area sources. The fundamental physical assumption of the model is that the steady-state spatial distribution of concentration from a continuously emitting point source is given by the Gaussian plume formula. It is assumed that meteorological conditions over short periods of time (on the order of one hour) can be regarded as steady state, and that those conditions can be approximated with a constant and spatially uniform wind speed and with a unique horizontal mean wind direction for the entire area.

The Gaussian plume formulas are used when there are no restrictions to dispersion in the vertical direction. When vertical dispersion is restricted to a finite mixing depth, a uniform vertical concentration distribution is assumed at substantial downwind distances.

Equations for the long-term average concentrations caused by point and area sources are weighted according to a frequency function to account for the variability of meteorological conditions. These empirical functions express the observed joint frequency of occurrence of various classes of wind direction, wind speed, and stability. Integration of the formulas over the area and point sources will describe the concentration that would be observed at selected locations for a certain set of meteorological conditions. These concentrations, taken

together with the frequency of occurrence of each combination of conditions, produce the required climatologically averaged spatial distribution of concentration.

The CDM contains provision for pollutant decay in the form of a function that allows for exponential decay with time (actually with distance from the source). It does not consider photochemical reactions of pollutants.

The following three modifications were made to CDM to make the model more appropriate to the Kern County oil fields. First, we modified the model to allow the emissions of up to 600 sources to be treated at one time in contrast to the 200 sources allowed by the original CDM.

Second, we inserted dispersion parameters and logic to more accurately simulate the rural conditions of the oil fields being modeled. Since CDM was originally developed for an urban area, the model's stability treatment required modifications that would allow the occurrence of more stable conditions (very stable conditions were not allowed to occur in the original CDM, since the heat island effect of cities enhances mixing).

CDM was designed to use surface wind speed and direction measurements (nominally taken at 10m). The model then applies a wind-speed profile to compute the wind speed at the effective stack height. For the computations made in this study, meteorological measurements taken at three locations were used; the measurement height at one of the locations was 45.7 m, whereas at the other two stations it was 9.5 m (see Subsection IV-B for description of meteorological sites). The third modification to CDM, used for the site where 45.7 m measurements were available, allowed CDM to accept the 45.7 m value as the value of the profile wind speed at that height.

The CDM was developed to predict seasonal or annual average pollutant concentrations. In this study the model computed annual average concentrations using the meteorological joint-frequency distributions discussed in Section IV-C-3.

Various models were examined for use in the computation of short-term average concentrations. In particular, consideration was given to a model named SRIPUFF,² that is capable of treating temporal and spatial variation in meteorological parameters. This is done by approximating continuous emissions from a series of stacks with a series of discrete puffs that are advected according to the prevailing winds and diffuse according to the estimated Pasquill-Gifford atmospheric stability class. It was the original intention to use SRIPUFF to compute the short-term average concentrations for central and western Kern County. However, a survey of available data sources revealed that the amount of data available for Kern County precluded application of SRIPUFF. To be truly useful, any model with the capability of following pollutant trajectories requires input data with which to generate a curvilinear wind field. In the case of central Kern County, wind measurements from a minimum of six locations would be needed to characterize the flow regime around and near the bluff on the northern edge of Bakersfield. (The bluff is described in Section IV-A.) In central Kern County only a single point wind measurement was available, so the puff treatment would simplify to a simple steady state Gaussian model. Little would be gained by using a computationally expensive puff model that would give essentially the same results as a steady-state Gaussian model.

Therefore, the CDM was used to compute 1-, 3-, and 24-hour average concentrations. CDM was chosen for the following reasons:

- The model has already been adapted to the large number of sources present in Kern County.
- The large number of sources compensates for the sector averaging done by the model. (This is discussed further below.)
- On a number of calibration runs made with the CDM for 1-hour average concentrations, good agreement between computed and measured values was reached.

The CDM can compute the concentrations that occur under 576 different combinations of wind speed, wind direction, and stability. As discussed previously, seasonal or annual average concentrations are found by computing the concentration at each receptor for each of the 576 meteorological combinations and then weighting the concentration according to

the frequency of occurrence of each set of meteorological conditions. If a short-term average is to be computed for a period during which only one or a few sets of meteorological conditions occur, zeros can be entered in the frequency distribution for all but the desired combinations, to which all of the weighting would be assigned. It was by creating such "false" frequency distributions that short-term average computations were made for the worst-case meteorological conditions (see the discussion of worst-case meteorology in Section IV-C-4).

There is one potential problem with using the CDM to compute short-term averages: the concentrations computed using the CDM formulation are crosswind-integrated concentrations. That is, the computed concentration is the average concentration over the plume in the crosswind direction. Thus, if a receptor is located on the centerline of the plume, the concentration computed at that receptor will not be the peak centerline value but rather will be the crosswind integrated concentration at that distance. The rationale for using such a formulation to compute long-term average concentrations is that the variation of wind directions and speeds that occurs in a relatively long data sample is sufficient for a crosswind integrated concentration to be representative of the long-term average concentration. For a small number of point sources, the use of the CDM to compute short-term average peak concentrations is inappropriate. However, for a large number of fairly densely located sources, the effects of a crosswind-integrated concentration in reducing concentrations at receptors located on the plume centerline should be balanced by the effect of increased concentrations at receptors located near the edge of the plume. Since the concentration at each receptor is comprised of concentrations resulting from a number of sources, the effects discussed above should compensate on a receptor-by-receptor as well as on an overall basis.

IV MODEL INPUT DATA

A description of the location and terrain of the study area is given in the first section of this chapter, followed by a description of the input data required by the models to compute existing case and future case SO_2 concentration patterns for both the central and western Kern County oilfields. Next we describe both generator and nongenerator source data and present the results of the generator location verification effort. Then, we discuss the meteorological sites and data. The process by which frequency distributions were produced and worst-case meteorology chosen are described. Finally, we describe the air quality measurement sites, analyze their suitability, and present the available air quality data.

A. Description of the Study Area

Essentially two separate areas in Kern County, California are to be modeled in this study. Both lie in California's Central Valley and hence will be influenced by the valley flow regime.

In central Kern County, the oil field having the highest density of steam generators is the Kern River Field, located just north of Bakersfield. Other nearby oil fields, such as the Kern Front, Round Mountain, Kern Bluff, and Mount Poso fields are included in the central Kern County modeling area. The terrain in the Kern River field is essentially flat. The other fields to the north are located in rolling hills, whereas the fields to the south are more or less flat. On the northern edge of Bakersfield (and the southern edge of the Kern River Field) is a bluff about 90 m in height. Bakersfield is situated atop the bluff, and the Kern River oil field is 90 m below. The location of the bluff is shown by hatched lines in Figure 1 in Section IV-B-1.

The study area in western Kern County is located on a roughly NNW to SSE line about 60 km due west of Bakersfield. The oil fields stretch from the Lost Hills Field in the north to south of the town of Maricopa,

a distance of about 70 km. Well to the west of the oil fields is a range of hills, the Temblor range. Most of the Western Kern County oil fields are flat. However, the Temblor Range can be expected to exert some influence on the winds in the area.

Since the north-south extent of the western Kern County oil fields is so great, the source inventory was divided into two parts. Meteorological data were measured at two locations, one in the north and one in the south portion of the area, to characterize the differences in the flow over the northern and southern parts of the region.

B. Source Data

1. Generator Location, Size, and Emissions

The steam generator source emission inventories for both the central and western Kern County oil fields were obtained from Science Applications, Inc. (SAI). The source lists were in CDM-compatible format, and contained the following information for each generator: x and y coordinates, relative to SAI's coordinate system; SO₂ emission rate; stack height; stack diameter; stack gas exit velocity; stack gas temperature; and SAI-assigned oil company identification symbol. As part of this study a limited verification analysis was performed on the emission inventories. The results of this verification are presented in Section IV-B-2.

Six generator source emission inventories were used in model calculations. The six inventories are: (1) central Kern County, existing case; (2) central Kern County, future case; (3) north portion of western Kern County, existing case; (4) north portion of western Kern County, future case; (5) south portion of western Kern County, existing case; and (6) south portion of western Kern County, future case. A listing of the inventories for each of these cases appears in Appendices A through F. Table 2 contains a list of the number of generators in each of the six inventories. Figures 1 and 2 show the locations of the existing and future Kern River area steam generators, classified according to emission rate. Figures 3 through 12 illustrate the locations of the existing and future generators in western Kern County. The symbols

Table 2

NUMBER OF GENERATOR SOURCES FOR EACH MODEL SIMULATION

Location	Case	No. of Sources*
Central Kern County	Existing	315
Central Kern County	Future	297
Western Kern County, north portion	Existing	192
Western Kern County, north portion	Future	238
Western Kern County, south portion	Existing	230
Western Kern County, south portion	Future	307

* The numbers listed in this column refer to the number of individual stacks. Manifolded units count as one source, even though several generators may comprise the manifolded unit.

representing generators were located manually using information contained on computer-generated plots. The locations shown are approximate because: (1) the SAI coordinate system was inconsistent, yet the coordinates in the inventories are based on that system (see discussion of source location verification in the following subsection); and (2) the computer plotting routine consolidated groups of sources into one location in areas where sources were of sufficient density to prevent computer delineation of each source's location and emission rate. Nevertheless, the figures illustrate the density and approximate locations of the emissions arising from the steam generators.

A listing of the output in British Thermal Units (BTU) of each generator is not given, since it was not supplied by SAI for all generators. However, for the existing case it was possible to identify the thermal output of many of the sample generators, and these values were used in the emission rate verification discussed in the following subsection.

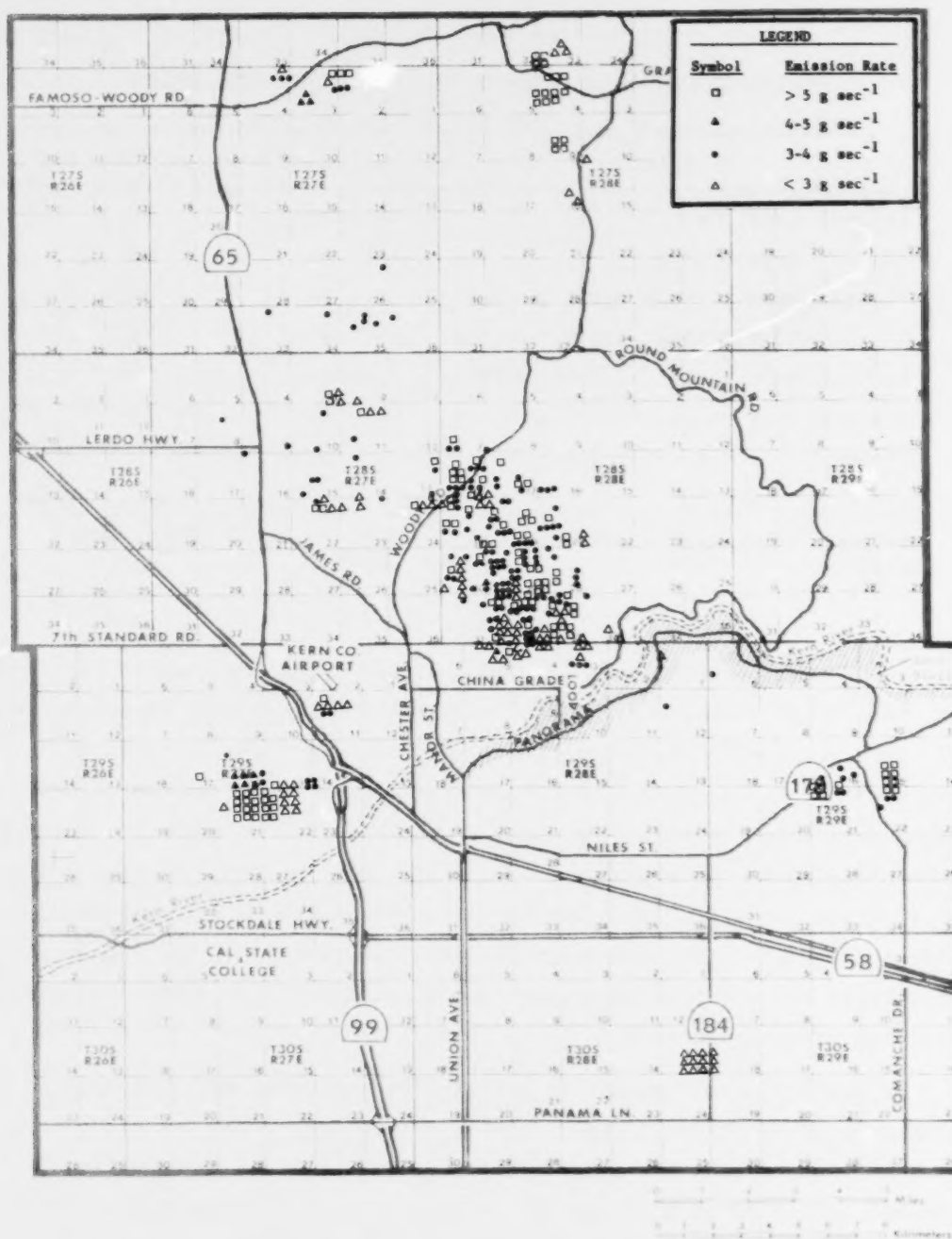


FIGURE 1 EXISTING STEAM GENERATORS AND OTHER SO₂ SOURCES IN THE CENTRAL KERN COUNTY OIL FIELDS

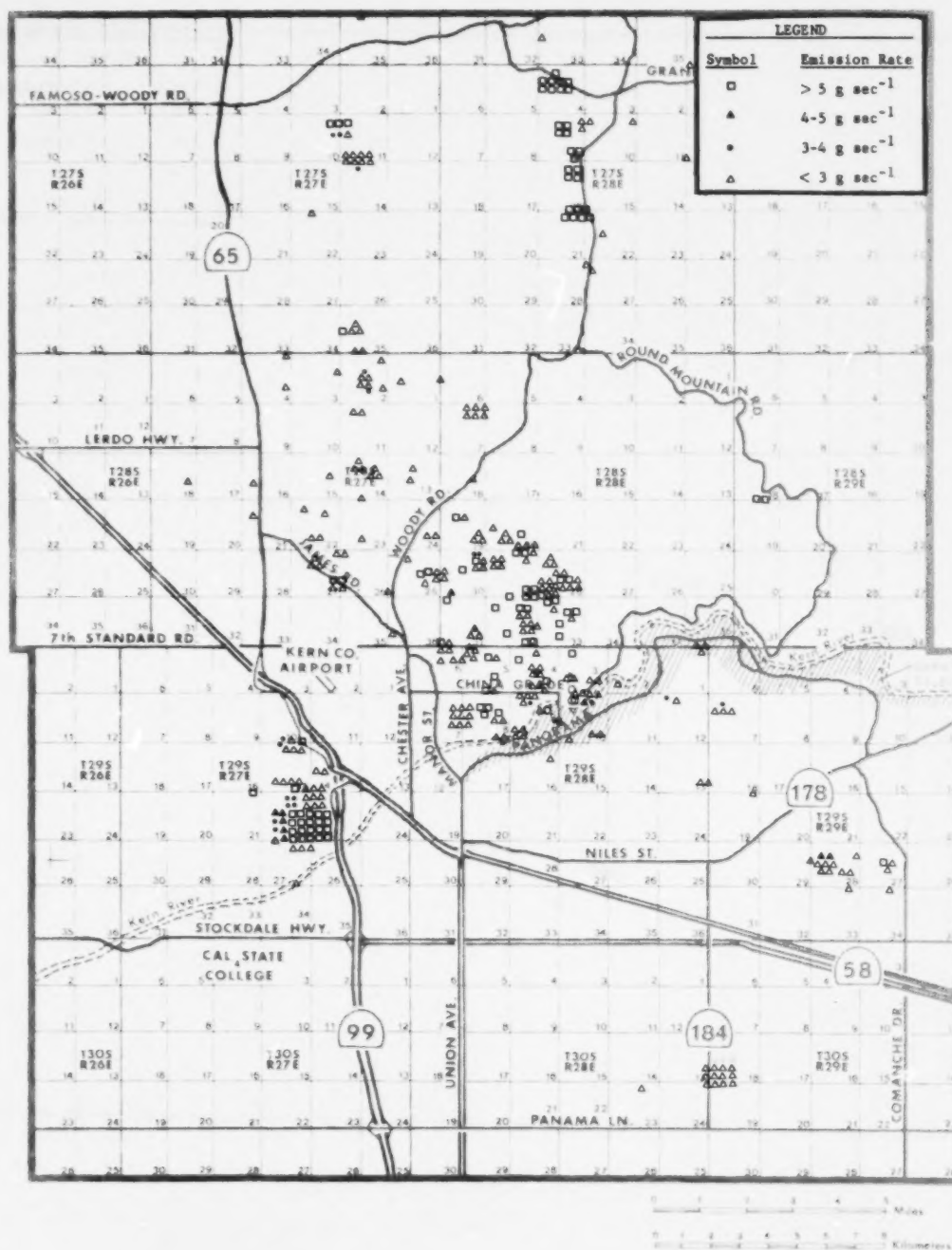


FIGURE 2 STEAM GENERATORS (EXISTING, PENDING, AND PROPOSED) AND OTHER SO₂ SOURCES IN THE CENTRAL KERN COUNTY OIL FIELDS

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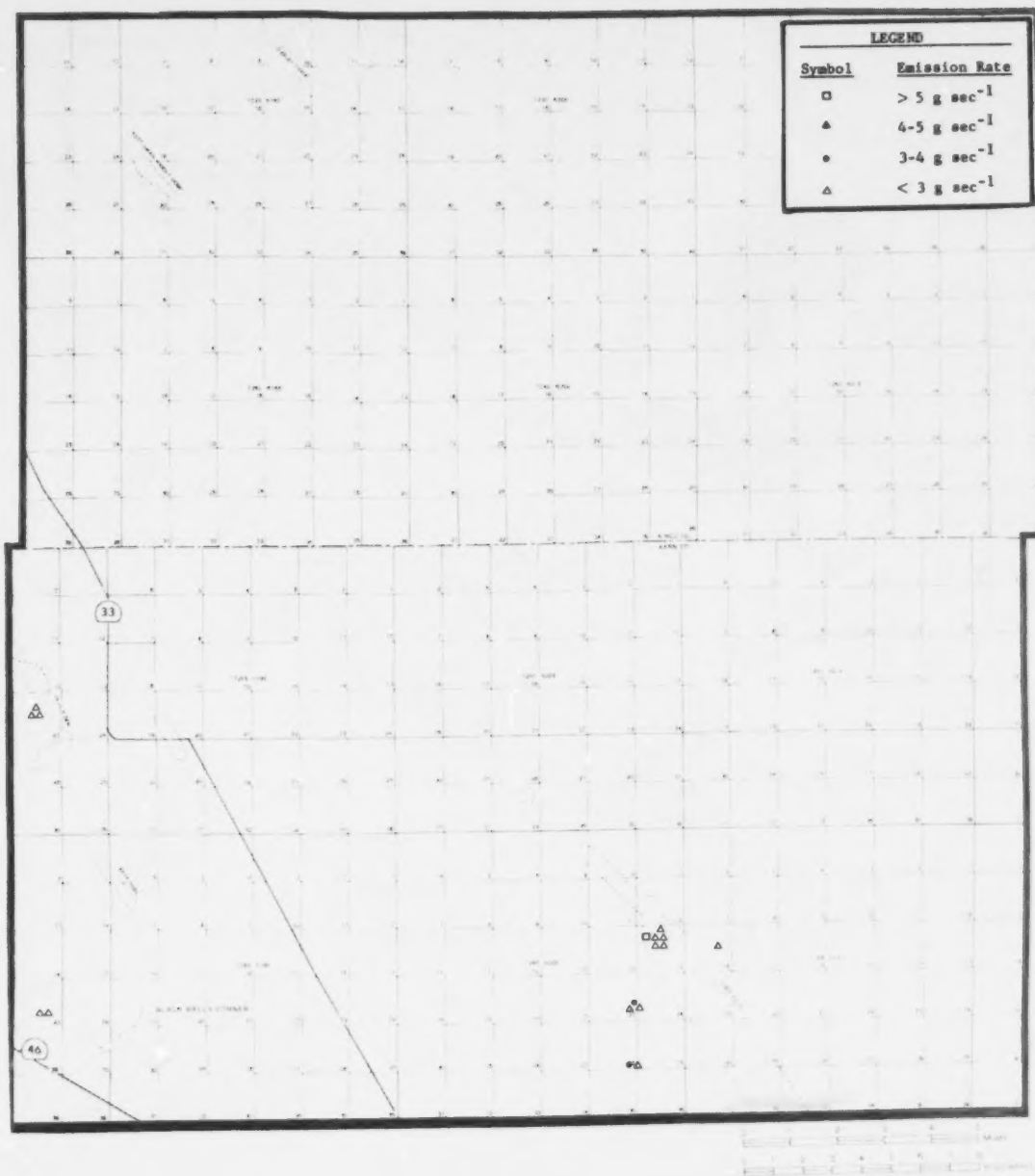


FIGURE 3 EXISTING WESTSIDE STEAM GENERATORS, NORTHWEST KERN COUNTY AREA

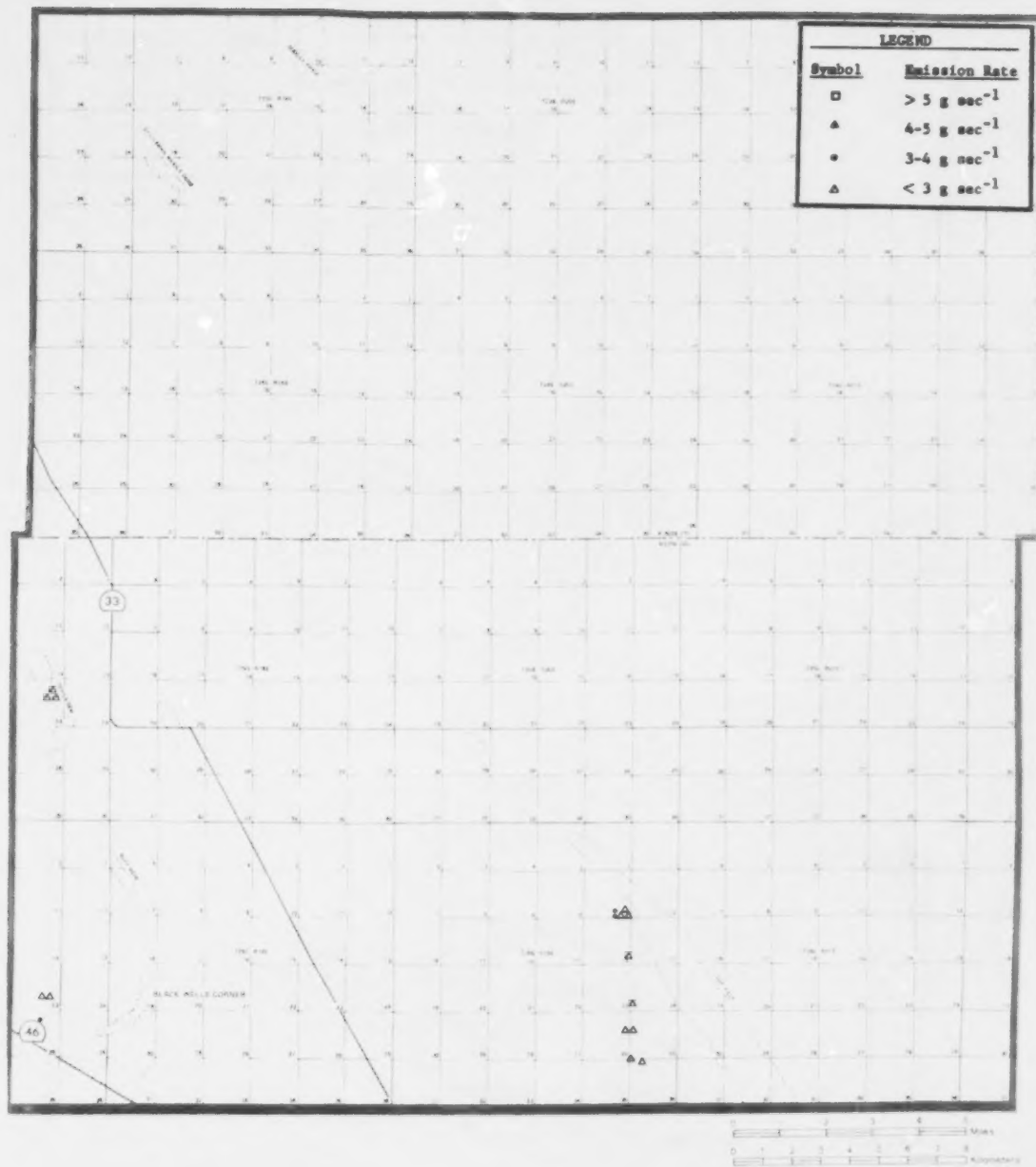


FIGURE 4 STEAM GENERATORS (EXISTING, PENDING, AND PROPOSED) IN THE NORTHWEST KERN COUNTY AREA

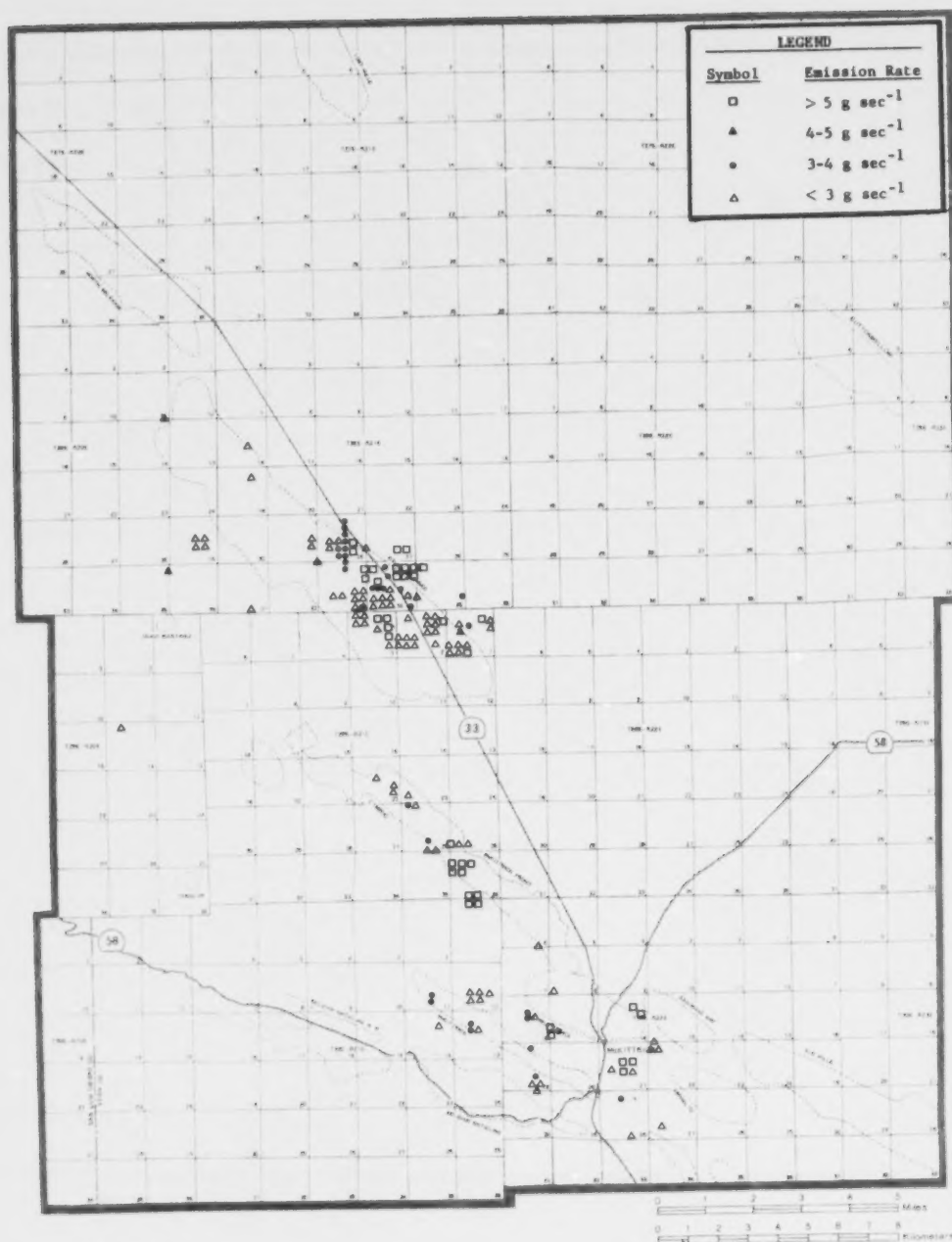


FIGURE 5 EXISTING WESTSIDE STEAM GENERATORS, BELRIDGE-McKITTRICK AREA

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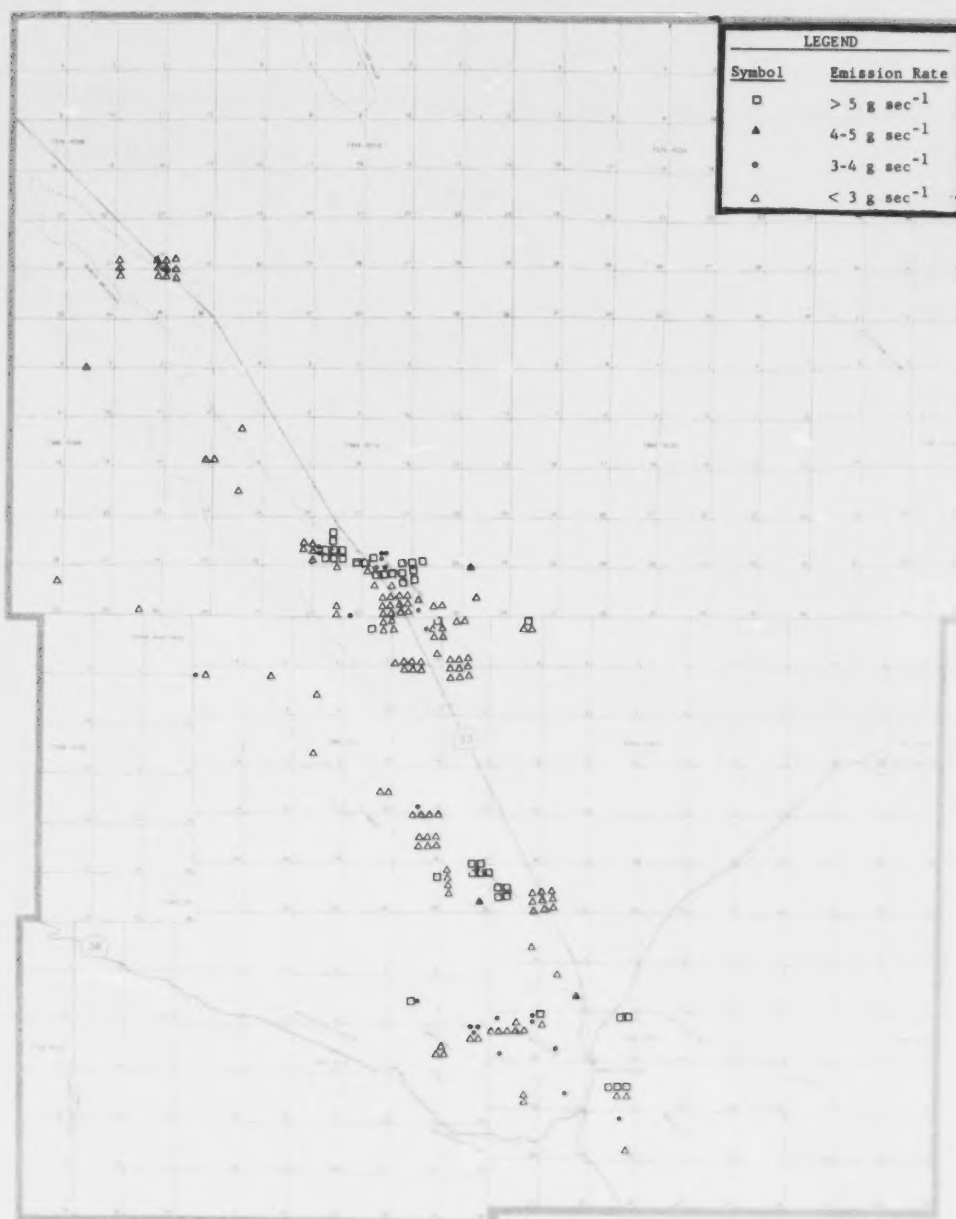


FIGURE 6 STEAM GENERATORS (EXISTING, PENDING, AND PROPOSED) IN THE
BELRIDGE-MCKITTRICK AREA

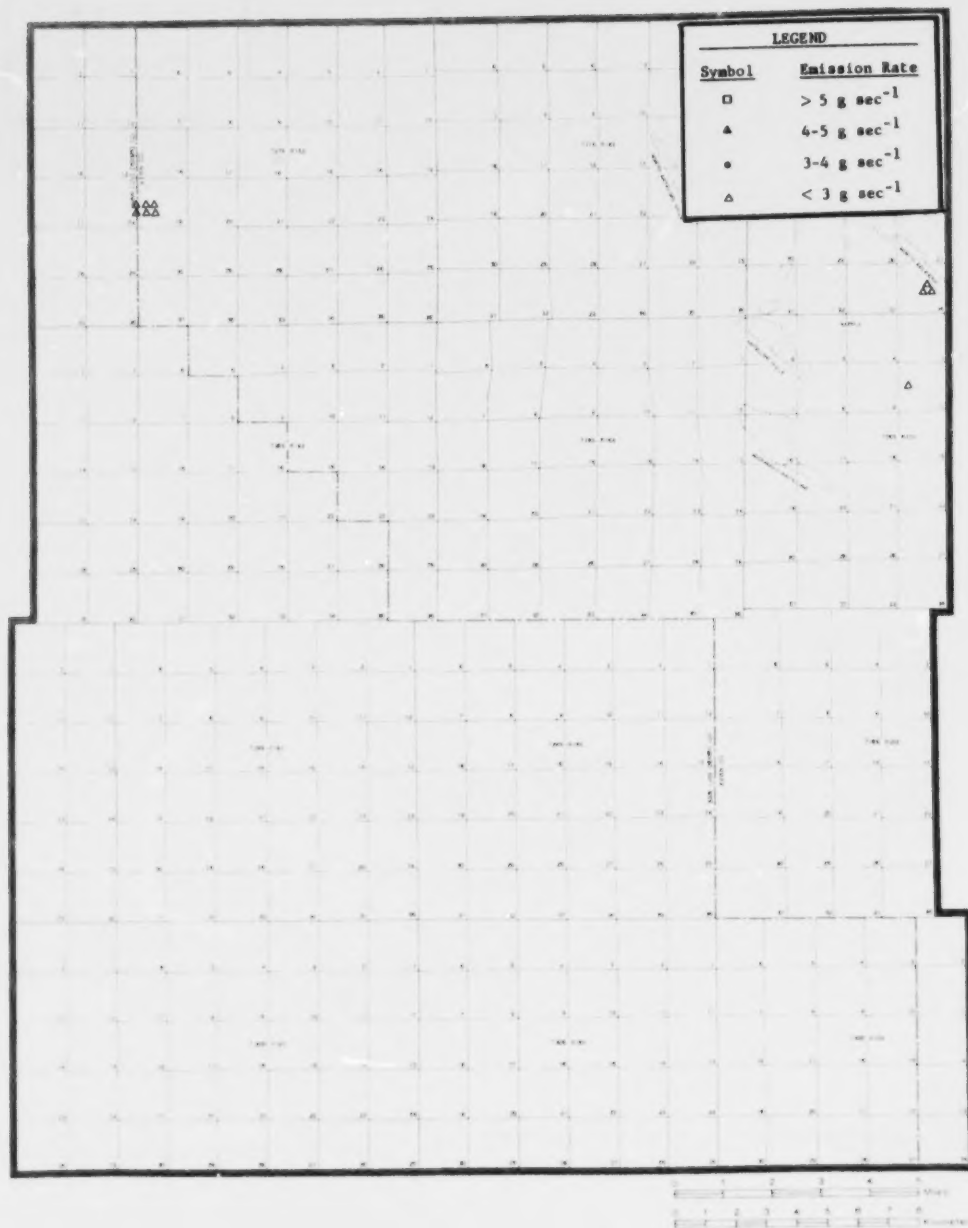


FIGURE 7 EXISTING WESTSIDE STEAM GENERATORS, WEST OF
BELRIDGE-McKITTRICK AREA

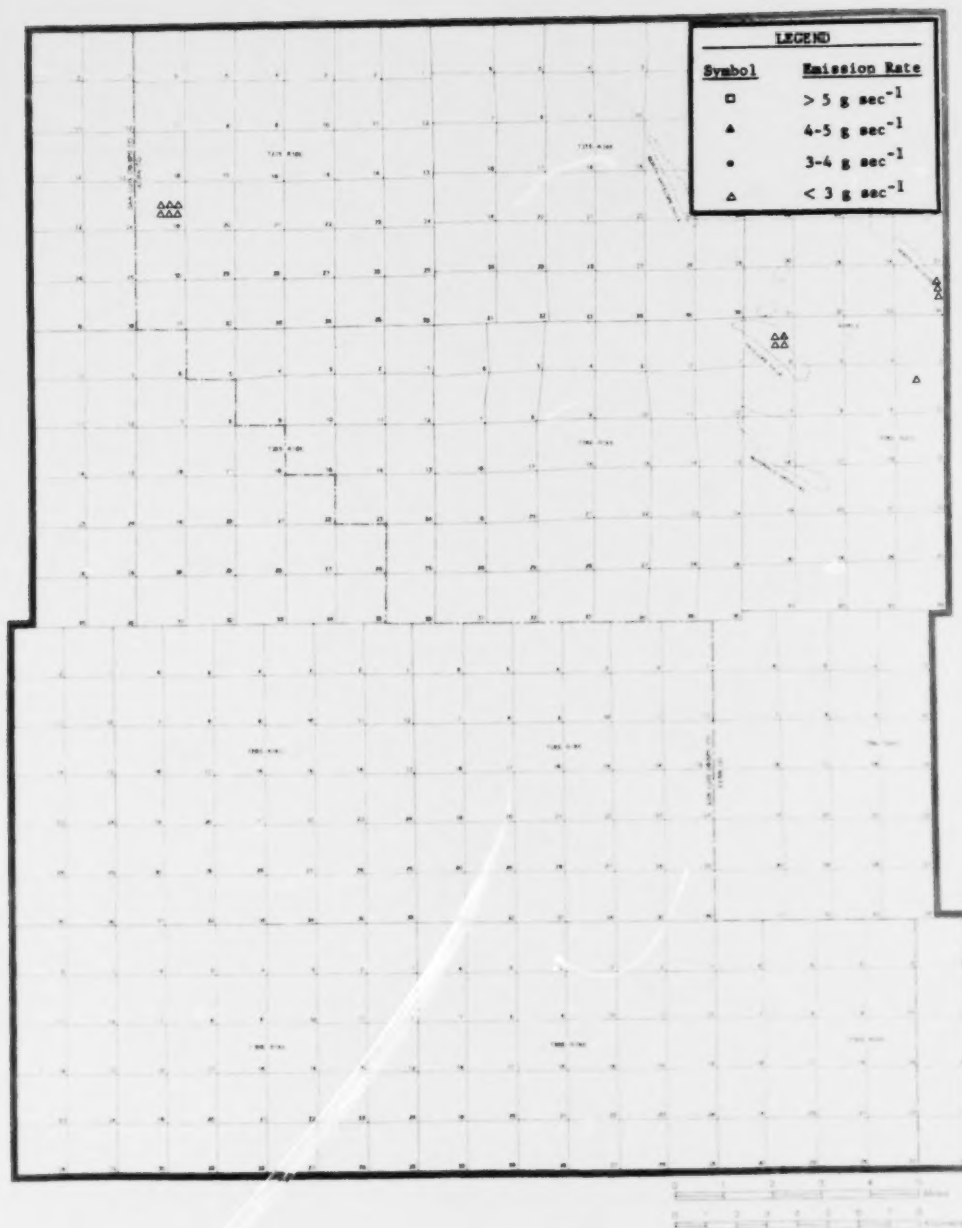


FIGURE 8 STEAM GENERATORS (EXISTING, PENDING, AND PROPOSED) WEST OF BELRIDGE-McKITTRICK AREA

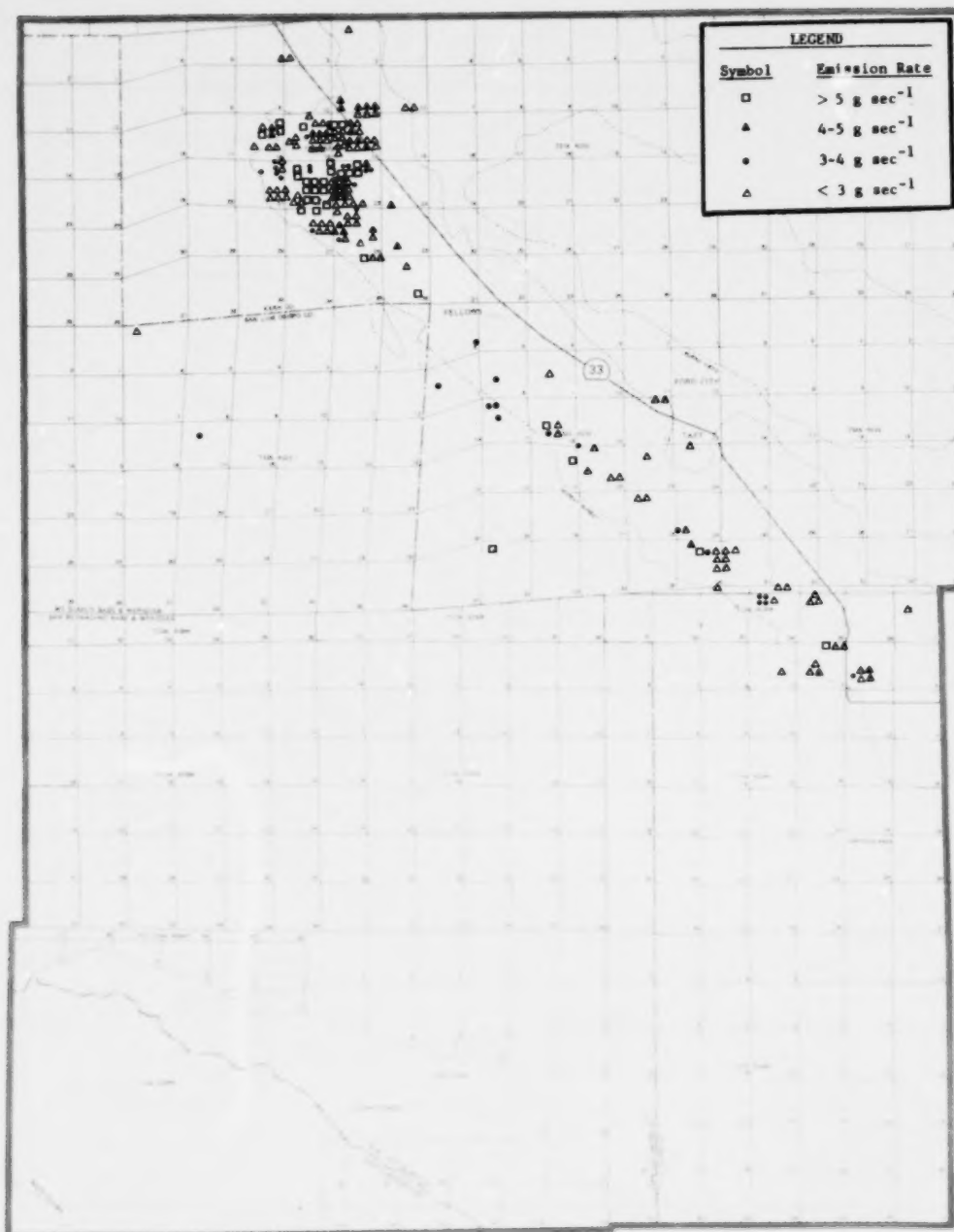


FIGURE 9 EXISTING WESTSIDE STEAM GENERATORS, FELLOWS-TAFT AREA

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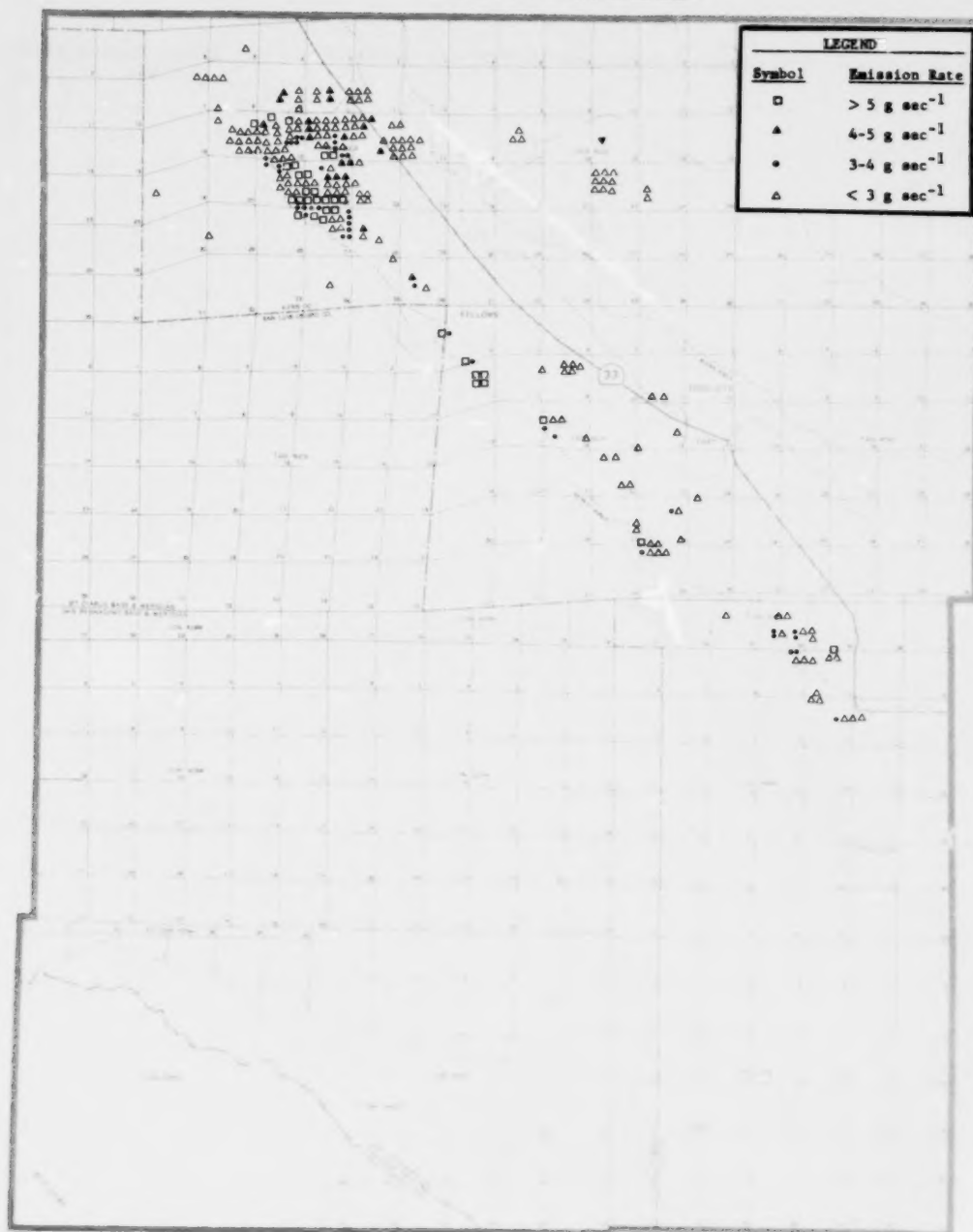


FIGURE 10 STEAM GENERATORS (EXISTING, PENDING, AND PROPOSED) IN THE FELLOWS-TAFT AREA

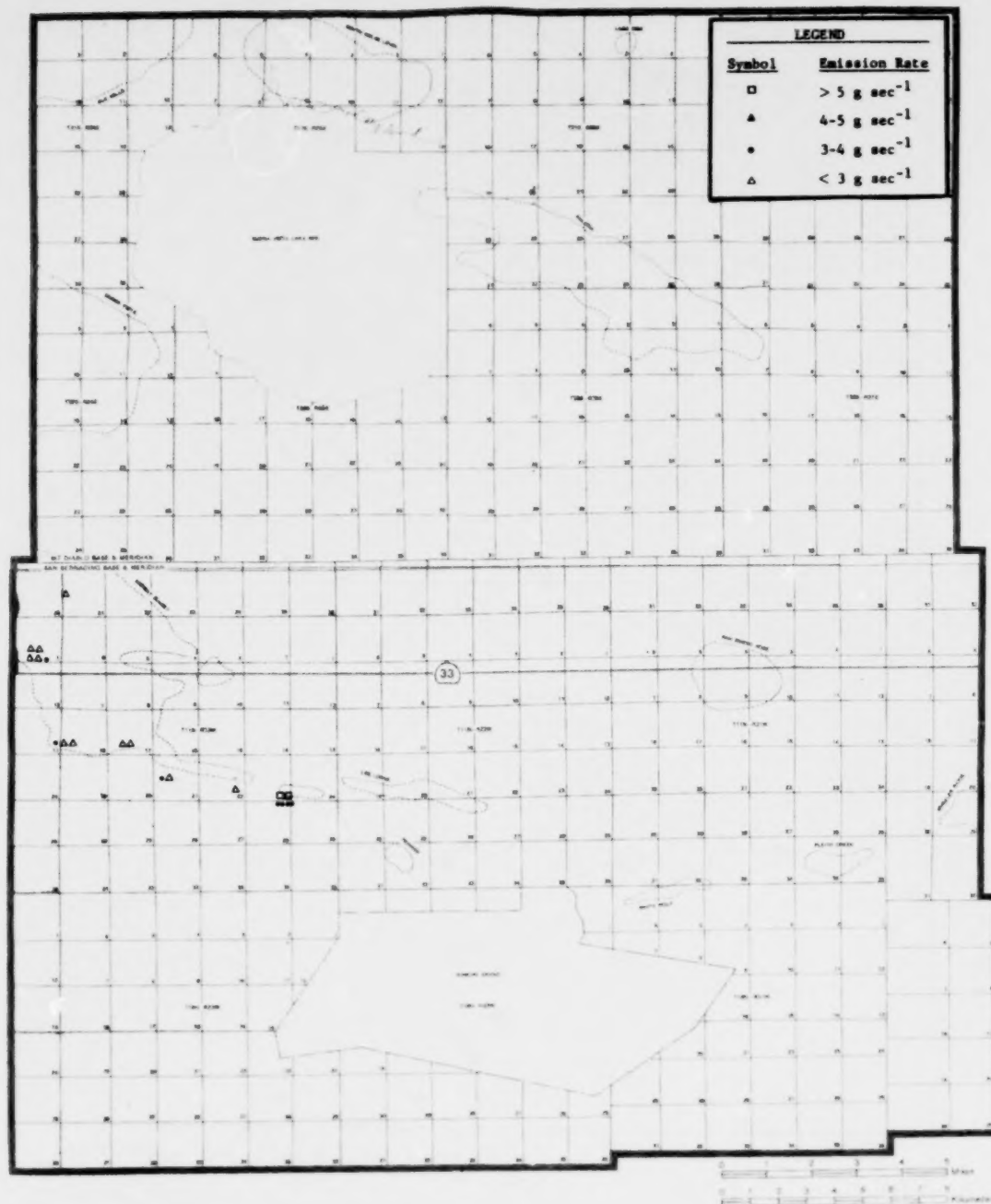
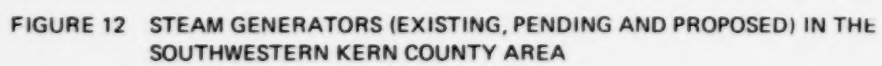


FIGURE 11 EXISTING WESTSIDE STEAM GENERATORS, SOUTHWESTERN KERN COUNTY AREA



2. Generator Source Data Verification

a. Location

The primary emphasis in the source data verification portion of this study was placed on the verification of the physical locations of the steam generators. There are approximately 315 generators in the Kern River oil fields near Bakersfield and about 420 generators in the western Kern County oil fields. Physically locating such a large number of generators was considered beyond the scope of this effort. However, we felt that useful information of a general nature could be gleaned from analysis of location data for a sample of generators. Therefore, we chose a random sample of generators for each of the above named regions, and located these generators. The number in the samples comprised about ten percent of the total existing as of April, 1977. The samples were chosen so that the generators in the samples: (1) were about ten percent of the total number of generators belonging to each oil company; (2) had BTU output rating distributions similar to those of all the generators; and (3) were, for the most part, randomly distributed in physical location.

During a field trip to the Bakersfield area we located each generator in the samples on large-scale California Department of Oil and Gas (DOG) maps. DOG maps were used because they give accurate locations of the numerous oil wells in the area. The wells are clearly marked in the field and could be used as aids in determining map locations of the generators. The parameters used to identify a generator as one of the sample chosen from the SAI inventory were the following: (1) section, township, and range; (2) oil company ownership; (3) BTU output rating; (4) stack height and diameter; and (5) SAI coordinates, plotted on the DOG maps. Given these parameters, little ambiguity existed as to which generator in the field matched which generator in the sample inventory. Once a generator had been identified as the one under verification, the DOG map location corresponding to the generator's physical location was determined using distances and directions from nearby oil wells, roads, or other landmarks appearing on the DOG maps.

Since the source inventory obtained from SAI was to be used in our model calculations, the actual field locations of the generators in the samples were compared with the coordinates assigned them by SAI. Using the SAI coordinates of a number of map locations (i.e., corners of sections) as reference points for gridding the DOG maps, we plotted the sample generators on the DOG maps at the SAI coordinates. The differences in the x (east-west) and y (north-south) directions between the SAI and actual locations were then measured and tabulated. The magnitude of the distance between the actual and SAI locations was analyzed. The analysis included examination of error in the following categories: (1) x-coordinate; (2) y-coordinate; and (3) angle of error vector from north. We hoped inclusion of these categories would aid us in possible correction of significant, systematic error. For example, if the overlaid grid used for determining x, y coordinates had been inadvertently shifted from the reference points while someone was reading generator coordinates, the coordinates would all be in error by an equal amount in the same direction.

Table 3 lists the average error in the x and y coordinates and the average error vector magnitude for the sample generators in the central Kern County fields, the western Kern County fields, and for both samples taken together.

Table 3
AVERAGE GENERATOR LOCATION ERROR

Parameter	Average Error (m)		
	Central Kern Co.	Western Kern Co.	Both
Δx	3.7	-241.	-120.
Δy	- 73.0	6.5	- 40.
error vector magnitude	211.0	380.	294.

Delta x and delta y are found by subtracting the appropriate coordinate of the actual generator location from the corresponding SAI generator coordinate. The SAI coordinate system is very nearly aligned with the positive y-direction to the north and the positive x-direction to the east. Therefore, it is apparent, for the central Kern County oil field generator sample, that mislocations of the east-west coordinate to the east and to the west are approximately equal on the average, whereas mislocations of the north-south coordinate favor a southerly direction. For the western Kern County generator sample, east-west coordinates are on the average erroneous in predominately a westerly direction, whereas north-south coordinate errors are approximately balanced in both the north and south directions. The magnitude of the average error vector is computed by summing the magnitude (absolute value) of each individual error vector and dividing by the number of generators in the sample. The table shows that the magnitude of the average error vector is greater for the western Kern County generators than for the central Kern County generators. This will be discussed later in this section.

Table 4 shows the distribution of x, y coordinate errors for generators in both central and western Kern County. The percentage of the sample having error in each of the directions (north, south, east, west) as well as the distribution of error magnitude is apparent from examination of this table.

Although it is informative to study location error by components, the direction and magnitude of the vectors connecting SAI locations with actual locations should be examined. To analyze the direction of location error, the 360 degrees of the compass were divided into eight 45 degree segments. For each generator sample the percentage of error vectors falling in each of the eight segments was computed. Figure 13 illustrates the results of these computations. In the figure the center of each group of error bars represents the actual location of a generator, while the ends of the bars radiating from the center represent the corresponding SAI generator location. The directions of the eight bars are the vector bisectors of the 45 degree segments, with the length of the bar proportional to the percentage of sample generators whose error

Table 4

RESULTS OF ERROR ANALYSIS OF SAI-ASSIGNED
GENERATOR LOCATIONS

Error in x(m)	Percentage of Sample		Error in y(m)	Percentage of Sample	
	Central Kern Co.	Western Kern Co.		Central Kern Co.	Western Kern Co.
0 to 100	30	12	0 to 100	22	8
0 to 300	49	20	0 to 300	33	23
> 0	60	20	> 0	33	35
0 to -100	19	8	0 to -100	33	31
0 to -300	34	39	0 to -300	63	62
< 0	40	80	< 0	67	65

vectors lie in that 45 degree segment. In Figures 13a and 13b the magnitude of the error bars represent a percentage of generators in the sample. For the central Kern County generators the error is for the most part distributed in all directions. Western Kern County generators, however, were mislocated mostly to the south through northwest. Figures 13c and 13d show a similar distribution, but in these figures the length of an error bar is proportional to the ratio of the error in that direction segment to the total error in all directions. The weighted directional error distribution for the central Kern County generator sample (Figure 13c) is similar to the unweighted distribution in Figure 13a. But the weighted distribution for western Kern County shows even a larger amount of the total error in mislocation of the sources to the south through northwest than does the unweighted distribution.

It was thought that if generator location error were systematic an overall correction factor could be applied to all generator locations. In the case of the central Kern County fields, analysis has shown the error to be fairly random and not readily correctable. The western Kern County SAI generator locations do exhibit a marked tendency toward mislocation in a generally westerly direction. However, the strong directional nature of the mislocation is spread over a range of directions

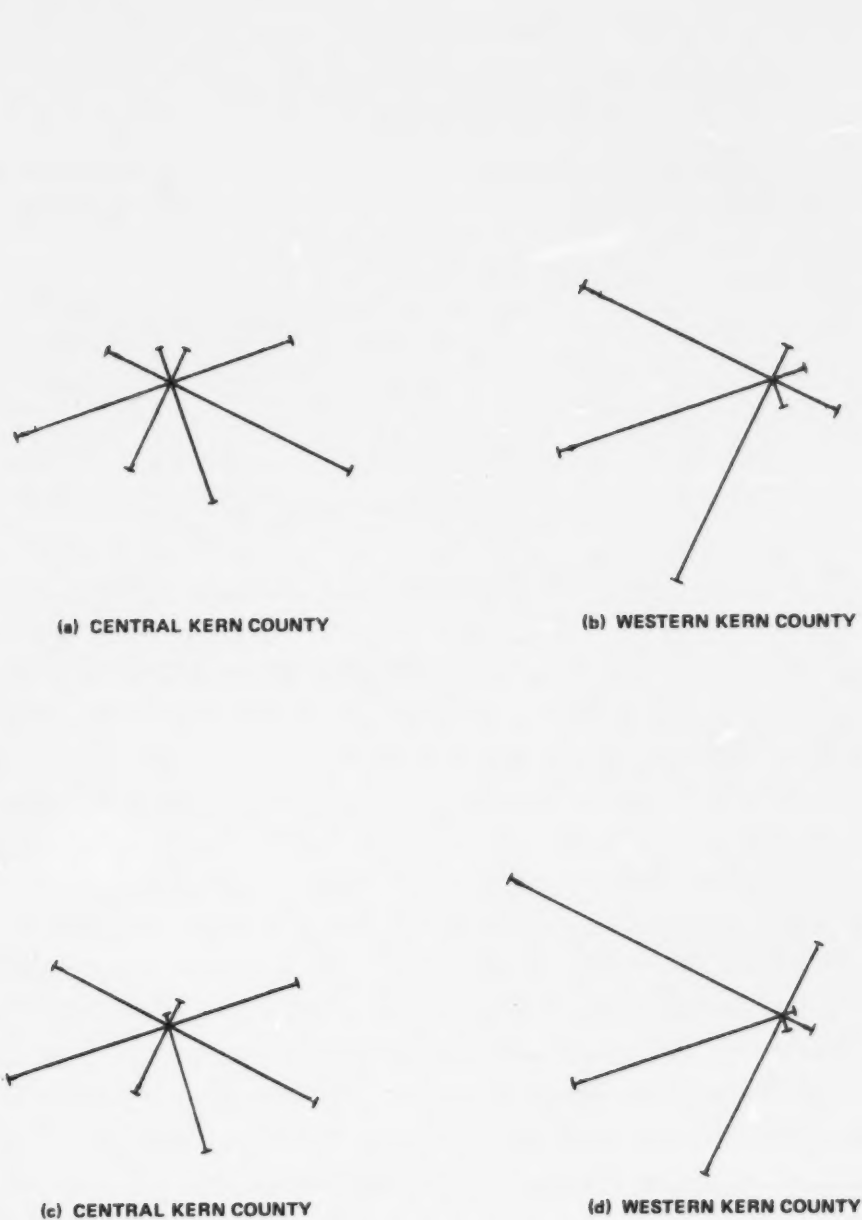


FIGURE 13 GENERATOR LOCATION ERROR BY DIRECTION.

Parts (a) and (b) Show the Percentage of Generators Having Location Error in Each Direction; Parts (c) and (d) Show the Percentage of the Total Location Error Magnitude for All Sampled Generators that Lie in Each Direction

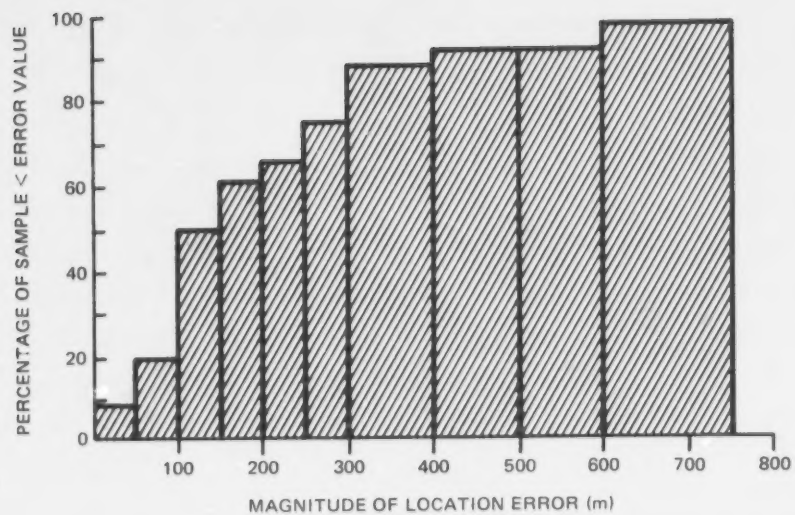
wide enough to preclude application of a general correction factor. It is felt that the use of a correction factor would introduce yet another source of error and that the benefits of such a measure would not outweigh the disadvantages.

The final part of the location error analysis involves examination of the distribution of error magnitude. Figure 14 shows histograms of the cumulative frequency distributions of the magnitude of location error for each of the generator samples. The histograms are drawn such that the height of a column gives the percentage of the sample having error less than the error value read at the right-most edge of the column. For example, Figure 14b shows that 33 percent of the sample had location error less than 250 m.

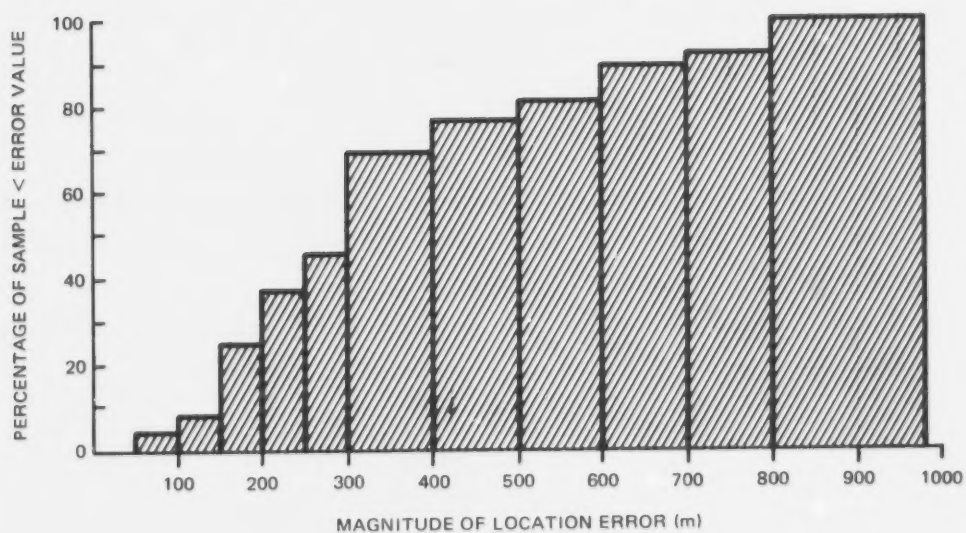
In general, location error was less for generators in the central Kern County oil fields than for the western fields. From Table 3 it was seen that the average error magnitude for the central Kern County generator sample is 211 m, whereas for the western Kern County sample it is 380 m. The standard deviation of the central Kern County sample error is 162 m. For western Kern County the standard deviation of location error is 228 m.

It should be noted that two of the sample generators could not be located within a reasonable distance of their SAI-assigned locations. However, concrete pads where generators had once been mounted were found in the area of each SAI location, so it was assumed the units in question were not portable. Since such a small percentage of the sample had been moved, we can reasonably assume that the inventory contains few units no longer located at or near their assigned coordinates.

Generator location error appears to arise from two causes. First, and probably more important, was the inaccuracy or inexactness of the location data available from the oil companies. In some cases an oil company did not really know where its generators were located. In many instances the oil companies could resolve their generator locations no closer than the section number and the quadrant within that section. This forced SAI to assign locations based on the best available information.



(a) KERN RIVER OIL FIELDS



(b) WESTSIDE OIL FIELDS

FIGURE 14 CUMULATIVE FREQUENCY DISTRIBUTION OF MAGNITUDE OF LOCATION ERROR

Discussion with SAI personnel revealed that their methodology for assignment of location involved taking the most conservative approach; that is, assigning generator locations such that the highest pollutant impact would result from the assigned location.

The second cause of error results from what appears to be inexact gridding of the coordinate system on maps. The approach to gridding taken in this effort was to (1) use the largest scale maps available (large-scale DOG maps), and to (2) overlay the maps with a very accurately drawn, photographically produced acetate grid. In aligning this grid with the SAI coordinate system, difficulty was encountered in matching the grid with the SAI-supplied reference points. In many instances it was not possible to reconcile the SAI reference with what were the appropriate locations for those points on the SRI gridded maps. Using the scale of the large DOG maps, the distance on the maps between the chosen reference points often did not match the differences in SAI coordinates for those points. The most likely cause of this discrepancy was the methodology used by SAI to grid the maps. It appears that SAI began with small-scale maps overlaid with an acetate grid, read section corner coordinates from these maps, and transferred those coordinates to larger scaled maps. This coordinate transfer could result in the above noted discrepancies, since the large-scale maps give greater detail and resolution. However, this source of error would seem to be less significant than the problems resulting from the incompleteness of oil company data.

It was previously noted that generator location error in the central Kern County oil fields is considerably less than error in the fields in the western part of the county. The cause of this difference is apparently the result of the following. The central Kern County fields have been in existence for quite some time. In general, the oil companies having generators in these fields have documented their locations in greater detail than the locations of generators on the westside. In particular, Getty Oil Company has accurate locations for its generators, and since a large portion of the generators in the Kern River fields

belongs to Getty, the overall accuracy of the sample generator locations was improved.

The preceding discussions have shed some light on the amount of error in generator location to be expected. The issue now to be addressed is the effect of this location error on the pollutant concentration calculations. Undoubtedly error of the magnitude discussed above will have some effect. However, this effect must be evaluated in terms of the accuracy and dependability of the modeling effort in general. Concentration simulations depend on a number of factors in addition to source location: the ability of a model to simulate dispersion; the effects of surrounding terrain; the representativeness of meteorological parameters used in model computations; the availability of measured concentrations for model calibration purposes; the accuracy of other source characteristics; and so forth. In the central Kern County fields the generators appear to be mislocated in a more or less random fashion. Given this and considering the magnitude of the location error for this area and the state-of-the-art of air quality simulation modeling, the effect of generator location error on the location of concentration isopleths should be minimal. In western Kern County, while location error is larger in magnitude and more directionally oriented, a major population area such as Bakersfield is not located nearby. Therefore, while some effect may be expected on regionwide concentration patterns, it should be small and not of particular significance when considered in concert with the accuracy of present day air quality models.

b. Other Parameters

While the source data verification program concentrated primarily on generator locations, other source parameters were spot-checked. While locating the sample generators in the field, records were kept of the BTU output rating and stack height and diameter.

The BTU output ratings of the western Kern County generators (or boilers) matched closely with those designed in the source inventory. No discrepancies were noted. The output ratings for the central Kern County inventory were not supplied to us and hence could not be checked.

Calculations have been made of emission rates for sources with various BTU output ratings. To make a rough check on the emission rates listed in the inventories, average emission rates were computed assuming 1.1 percent sulfur. Although the emission rates listed in the inventories were computed from the actual percent sulfur used in the generator, spot checks showed good correlation between the emission rate computed from the BTU output of a unit as described above and the emission rate given in the inventory for that unit. Any discrepancies between the inventory emissions and computed emissions were within the variability of the percent sulfur burned in Kern County generators.

A few discrepancies between the stack heights and diameters observed in the field and those listed in the source inventory were noted. However, these were minor and the inventory was corrected. The locations of the generators sampled were also corrected in the inventory.

3. Nongenerator Sources

In central Kern County, near Bakersfield, several facilities other than steam generators exist that emit sulfur dioxide. These sources, called "nongenerator sources" in this report, are primarily oil refineries. The nongenerator source locations are shown along with the existing case generators in Figure 1 and with the future case generators in Figure 2.

A number of parameters that describe pollutant sources are required input data for CDM. Such parameters include stack diameter and height, effluent exit velocity and temperature, and pollutant emission rate. In many instances the only pieces of information available of the type listed above for nongenerator sources were the number of barrels of crude oil burned per day in each stack or the thermal output of each unit (BTU), and the sulfur content (percentage) of the fuel.

To compute an emission rate for each nongenerator source stack, one of two equations was used. To convert barrels (bbl) per day to an emission rate, the following equation was used, based on the latest SO_2 emission factor supplied by EPA:

$$E = \left(x \frac{\text{bbl}}{\text{day}} \right) \left(6.6 (\%S) \frac{\text{lb}}{\text{bbl}} \right) \left(\frac{1 \text{ day}}{24 \text{ hr}} \right) \left(\frac{1 \text{ hr}}{3600 \text{ s}} \right) \left(453.6 \frac{\text{g}}{\text{lb}} \right)$$

where E = stack SO_2 emission rate (g/s)
 x = amount of fuel burned (bbl/day)
 $\%S$ = percentage sulfur of the fuel

The number 6.6 is the emission factor for SO_2 , and the remaining numbers are unit conversion factors. To compute the stack emission rate from thermal output, the following equation was used:

$$E = \left(y \frac{\text{BTU}}{\text{hr}} \right) \left(\frac{1}{6.3 \times 10^6} \frac{\text{bbl}}{\text{BTU}} \right) \left(6.6 (\%S) \frac{\text{lb}}{\text{bbl}} \right) \left(453.6 \frac{\text{g}}{\text{lb}} \right) \left(\frac{1 \text{ hr}}{3600 \text{ s}} \right)$$

where y = thermal output of stack (BTU/hr)

Two SO_2 emission rates were computed for each stack. An annual average emission rate was computed using one of the above equations and a weighting factor that represents the percentage of the time that the stack is in operation during the year. A maximum emission rate was also computed using one of the above equations, but this rate was not weighted and was for use in short-term worst-case concentration calculations.

As was previously mentioned, stack parameters such as diameter and height and effluent exit velocity and temperature were not available for each individual stack. For some of the nongenerator sources, all of the parameters were available, for others some parameters were known, and for some sources no stack parameters at all, other than fuel usage, were available. To fill in unknown parameters, the following method was used.

First, if fuel usage was given in units of bbl/day, this was converted to units of BTU/hr. Next, all stacks for which some of the stack parameters were available were grouped according to thermal output. Ten groups of stacks were formed, according to the class intervals listed in Table 5. Distinction was made between heaters and boilers. For each class, the average stack height, stack diameter, effluent exit velocity, and effluent temperature were calculated for boilers and for heaters. The average values for each of these classes are presented in Table 5.

Table 5
AVERAGE STACK PARAMETERS OF VARIOUS THERMAL OUTPUT CLASSES FOR NONGENERATOR SOURCES

Thermal Output Interval (BTU/hr)	Stack Diameter (m)	Stack Height (m)	Exit Velocity (ms^{-1})	Gas Temperature ($^{\circ}\text{C}$)	Facility Type
0-5	0.7	10.4	7.9*	444	heater
5-10	0.7	13.6	7.9	441	heater
5-10	1.2	13.1	7.0*	450*	boiler
10-15	0.9	13.1	5.1	671	heater
15-20	1.1	20.2	4.0	469	heater
20-25	1.1	21.6	5.0	491	heater
20-25	1.6	27.4	6.0*	454	boiler
25-30	1.3	26.7	5.3	560	heater
30-35	0.9	13.7	7.0*	450*	heater
30-35	1.2	23.3	7.7	261	boiler
35-40	1.3	27.7	6.9	484	heater
60-70	2.0	34.9	8.2	438	heater
75-85	2.0	35.1	8.9	624	heater
75-85	2.0	30.5	11.6	615	boiler

* Estimates (no data available).

Thus, for those sources for which stack parameters were not known, the type (heater or boiler) and the thermal output of each unit was used to select the appropriate average stack parameters derived by the above method. These parameters, along with the actual emission rate, were then used for such sources in model computations.

The total number of nongenerator source stacks is 80. The nongenerator source inventory for central Kern County is listed in Appendix G. A list of the facility names, types, number of stacks, and the total thermal output of each facility appears in Table 6. The thermal output listed is from oil only; thermal output created by gas is not included.

C. Meteorological Data

1. Measurement Sites

Meteorological data are measured at two sites in central Kern County. One site is the National Weather Service station at Bakersfield airport. Although, in the past, hourly meteorological data were recorded at the airport station, since 1970 observations are taken at 3-hour intervals. The other central Kern County site was established by Getty Oil Company near Oildale, California. Because Aerovironment, Inc. had undertaken a study sponsored by Getty, they possessed a tape containing hourly meteorological data for a period of one year (1 July 75 to 30 June 76) at the Getty station. With Getty's permission, Aerovironment made the tape available to SRI. The meteorological data available included both surface (10 m) and 45.7 m wind speed and wind direction measurements, the temperature difference (ΔT) between 10 m and 30 m, the standard deviation of the horizontal wind direction fluctuation ($\sigma \theta$), and several other parameters.

Meteorological data are also measured at two sites in the vicinity of the western Kern County oil fields. The monitoring sites were established and are operated by SAI. The site chosen as representative of the meteorological regime of the northern portion of the westside oil fields is located in the Midway-Sunset oil field in Getty's field office

Table 6
NAME, TYPE, NUMBER OF STACKS, AND THERMAL OUTPUT OF NONGENERATOR SOURCE FACILITIES

Facility Name	Facility Type	Number of Stacks	Total Thermal Output (Btu/hr $\times 10^6$)
Kern County Refinery	refinery	15	266.9
West Coast Oil Co.	refinery	3	72.0
Sabre Oil and Refining Co.	refinery	2	29.1
Sunland Refining Corp.	refinery	1	0.8
San Joaquin Refining Co.	refinery	7	216.1
Mohawk Refinery	refinery	15	205.7
Golden Bear Refinery	refinery	9	27.5
Lion Oil Co.	refinery	27	1043.5
PG&E	power plant	1	75.4

yard, near Fellows, California. The elevation of the site is about 365 m mean sea level (MSL). The instruments are installed atop a 9.4 m pole. The site chosen to represent the meteorological regime in the southern portion of the westside fields is located in the Belridge Oil Company's field office yard in the South Belridge oil field. The site's elevation is approximately 600 feet MSL. The instruments are mounted on a boom 9.4 m above ground level. The upper ΔT sensor is mounted on a boom 43.9 m above the ground. Hourly wind speed, wind direction, and temperature at both sites and ΔT at the Belridge site were supplied by SAI for a one year period (1 May 76 to 30 April 77).

2. Determination of Stability

a. Central Kern County

Of the two meteorological data sources available for central Kern County, the Getty data were chosen for use in this study for the following reasons: (1) the data were collected at a site located right in the middle of the major oil field; (2) considerably more recent hourly data were available at the site than were available for the Bakersfield airport site; and (3) calculations showed that the 45.7 m wind measurement height coincided with the average effective stack height for the generators.

However, atmospheric stability class was not part of the data and had to be computed for each hour of each day from sigma θ measurements. First, the solar time of day was determined from the solar declination and elevation relationships shown below:

$$\delta = \arctan \{-0.43481 \cos [0.017214 (10 + N)]\}$$

$$\sin \alpha = \sin \delta \sin \phi + \cos \left[\frac{(H - 12)\pi}{12} \right] \cos \delta \cos \phi$$

where δ = solar declination angle

N = number of the day of the year (1 to 365)

α = solar elevation angle

ϕ = station latitude

H = hour of the day (1 to 24)

The hours between sunset and sunrise (nighttime) are those hours for which the sine of the solar elevation angle is negative. When the solar elevation angle is between 0 and 15 degrees, the solar time of day is considered to be sunrise or sunset. Hours for which the elevation angle is greater than 15 degrees are considered daytime.

Having determined solar time of day, and knowing the wind speed and sigma θ for the hour, one can select from Table 7 the atmospheric stability appropriate to the hour. This process was used to determine the stability of each hour of each day for the one year meteorological data sample taken at Getty's site.

The sigma θ intervals associated with various stability classes, given in Table 7, apply to rural conditions. To determine whether the Kern County oil fields could be represented most appropriately by rural or by urban conditions, the surface roughness in the fields was computed according to the following relationship as given by Lettau³:

$$z_o = 0.5h^* sn/A$$

where z_o = surface roughness parameter (cm)
 h^* = effective obstacle height (cm)
 s = silhouette area of average obstacle (cm²)
 n = total number of obstacles
 A = total area of the site (cm²)

It was assumed that the ground is essentially devoid of vegetation and that the only obstacles are steam generators or oil wells. Further, it was assumed that in the average oil field one-quarter of a square kilometer contains 75 obstacles having a cross-sectional area of 1.9 m² and a height of 3 m. Substituting these values into the above equation yields a surface roughness of 0.8 cm. In general a surface roughness parameter in excess of 50 cm denotes "urban" conditions, whereas the smaller surface roughness values represent "rural" conditions. Because the surface roughness calculated for the oil fields is small, the rural sigma θ intervals were used in this study.

Table 7

STABILITY CLASS AS DETERMINED FROM SIGMA θ ,
SOLAR TIME OF DAY, AND WIND SPEED*

Solar Time of Day	Solar Elevation Angle (degrees)	Wind Speed (m/s)	Sigma θ (degrees)	Stability Class No.	Stability Class Description
sunrise, sunset	0-15	≥ 0	-	4	day neutral
nighttime	≤ 0	> 0	> 8	5	night neutral
nighttime	≤ 0	0	≥ 0	6	stable
nighttime	≤ 0	> 0	≤ 8	6	stable
daytime	> 15	0	≥ 0	1,2†	very unstable, unstable
daytime	> 15	> 0	> 22.5	1	very unstable
daytime	> 15	> 0	17.5-22.5	2	moderately unstable
daytime	> 15	> 0	12.5-17.5	3	slightly unstable
daytime	> 15	> 0	≤ 12.5	4	day neutral

*This stability classification scheme is a combination of two published schemes. The method used in the APRAC air quality model⁴ was employed to classify stability near sunrise and sunset and at night; a method suggested by Gifford⁵ was used to classify daytime stability, according to sigma θ .

†In general, class 1 for hours 12-14, class 2 for other hours. However, each case should be examined individually.

b. Western Kern County

Meteorological parameters at the two western Kern County sites were measured by SAI. Stability was determined from ΔT , according to the commonly used scheme presented by Gifford.⁵ Although the stability typing scheme used is meant to translate ΔT into a Pasquill-Gifford stability class, in practice the scheme often produces a questionable stability frequency distribution. The problem with the scheme lies in the measurement of ΔT . The range of ΔT over 100 m in the vertical is, in general, 5°C or less. The differences between the ΔT corresponding to one stability class and that of the adjacent class may be as little as 0.2°C. The noise level in ΔT instrumentation approaches 0.2°C; hence, instrument error could quite easily cause stability to be erroneously classified.

In the case of the SAI instrumentation, ΔT was measured between 9.4 m and 43.9 m for a difference of 34.5 m. Since the measurement interval was considerably less than the 100 m interval for which the stability classification scheme was defined, SAI was forced to create a new ΔT interval to be associated with each stability class. These intervals were by necessity smaller than those in the original scheme, and hence even more subject to instrument error.

The stability distribution supplied by SAI is summarized and discussed in Section IV-C-3. It is a very unusual distribution, and it is probably considerably different from the distribution that would result from using insolation and wind speed to determine stability. That is, using the insolation/wind speed stability typing scheme, it would not be possible for stable conditions to occur as much as 50 percent of the time, since Pasquill-Gifford stability class 6 is allowed only at night. However, the SAI data shows the occurrence of stable conditions in excess of 50 percent of the time. In fact, neutral or stable conditions are reported for 92 percent of the time. At first glance, it appears that a preponderance of stable conditions is a conservative assumption in that annual average concentrations computed under those conditions will be higher than if less stable conditions had been assumed to occur more frequently. However, computations in Kern County have shown that in fact higher concentrations are obtained under neutral conditions than

under stable conditions. Hence, the frequency distributions obtained from SAI may cause lower concentrations to be predicted than would be predicted with an insolation/wind speed derived distribution.

The difficulties discussed above concerning the frequency distributions obtained from SAI would be cause for rejection of the data if another source of data for western Kern County existed. However, the only measurements made in western Kern County are those made by SAI, and the only other even somewhat nearby measurement sites are at Bakersfield airport and Getty's site near Oildale. The weather station at Bakersfield airport no longer reports hourly aviation observations; since 1970 observations are made every 3 hours. If hourly observations of cloud cover were available, the insolation/wind speed method of determining stability could be used with cloud cover from Bakersfield and wind speed and direction from the SAI monitors to produce a fairly realistic frequency distribution. However, the necessity of interpolating 3-hourly cloud cover observations to one-hour values would produce enough uncertainty that an improvement over the frequency distribution supplied by SAI would be doubtful. The data collected at the Getty site includes only sigma θ . While sigma θ is a very good means of determining stability, it could not be combined with wind directions and speeds from another location, since it is a measure of localized wind fluctuation. Additionally, the period for which the Getty meteorological data is on tape does not coincide with the period for which the SAI data were available.

Given the situation described above, the only alternative was to use the SAI data in the model simulations. Certain reservations should be made concerning the model results, however. It should be borne in mind that with regard to stability, the frequency distribution is heavily biased toward stable conditions, and that this bias could cause lower SO₂ concentrations to be predicted.

3. Meteorological Data for Long-Term Modeling

The long-term modeling of annual average SO₂ concentrations was done with CDM. The meteorological data required as model input for CDM consists of the following items: the average afternoon and nighttime

mixing heights for the modeled area, and the distribution of the joint frequency of occurrence of wind direction, wind speed, and stability. The average mixing heights used in the model were taken from Holzworth.⁶ The joint frequency of occurrence of wind speed, wind direction, and stability is represented by a fractional frequency distribution. Wind speeds are allotted to 6 classes, wind directions are divided into 16 classes, and stability is categorized according to 6 classes. The bounds of each class are listed in Table 8. From a long-term hourly meteorological record, the fraction of the time that each combination of the above classes occurs can be tabulated. The sources from which joint-frequency distributions for the study area were generated or obtained are discussed below.

Table 8

DEFINITION OF JOINT-FREQUENCY DISTRIBUTION CLASSES

Wind Speed		Wind Direction		Stability	
Class	Interval (knots)	Class	Interval (degrees)	Class	Description
1	0 - 3	1	11.25 - 33.75	1	very unstable
2	4 - 6	2	33.75 - 56.25	2	moderately unstable
3	7 - 10	3	56.25 - 78.75	3	slightly unstable
4	11 - 16	4	78.75 - 101.25	4	neutral (daytime)
5	17 - 21	5	101.25 - 123.75	5	neutral (nighttime)
6	>21	6	123.75 - 146.25	6	stable
		7	146.25 - 168.75		
		8	168.75 - 191.25		
		9	191.25 - 213.75		
		10	213.75 - 236.25		
		11	236.25 - 258.75		
		12	258.75 - 281.25		
		13	281.25 - 303.75		
		14	303.75 - 326.25		
		15	326.25 - 348.75		
		16	348.75 - 11.25		

a. Central Kern County

As previously mentioned, the meteorological data used for central Kern County were measured by Getty Oil Company. A joint-frequency distribution was generated from this hourly data. A computer program was used to classify the wind direction, wind speed, and stability (derived as discussed in Section IV-C-2) of each hour, and to tabulate the frequency of occurrence of each combination of wind direction class, wind speed class, and stability class during the one year period. Wind speeds and directions measured at 45.7 m were used to generate the frequency distribution, since the average effective stack height of the steam generators is near that level. A summary of the frequency of occurrence of each stability class, wind direction class, and wind speed class is given in Table 9. A listing of the entire distribution appears in Appendix H, in CDM-compatible format.

Since CDM has no provision to account for the effects of terrain, a second frequency distribution was generated in an effort to simulate the influence of the bluff on the northern edge of Bakersfield on dispersion. The basic assumption was made that air meeting the bluff at a right angle flows primarily around rather than over the bluff. The assumption of flow around rather than over isolated terrain features is substantiated in the literature.^{7,8}

Thus, to receptor locations downwind of the bluff, the pollutant is conveyed only from around the bluff. The pollutant emitted from sources directly upwind of such receptor locations, but below the bluff, will reach the receptors only by flowing around the bluff. To simulate this flow, the following method was applied.

First, the original frequency distribution was modified so that the frequency of occurrence of wind directions in the three sectors between 303.5 and 11.5 degrees from north (14, 15, and 16 in Table 8) were zero. Then the fractions of the year during which these winds occur were distributed among the wind direction classes adjacent to the above sectors. Since the perpendicular to the bluff lies at about 345° and the borderline between sectors 15 and 16 is 348.75°, the fraction of winds from

Table 9

ORIGINAL AND ALTERED JOINT-FREQUENCY DISTRIBUTIONS--
KERN RIVER SITE

Stability Class	Frequency of Occurrence	Wind Direction Class	Frequency of Occurrence	
			Original Distribution	Altered Distribution
1	0.06	1	0.03	0.10
2	0.08	2	0.04	0.05
3	0.14	3	0.07	0.07
4	0.35	4	0.10	0.10
5	0.17	5	0.04	0.04
6	0.21	6	0.04	0.04
		7	0.03	0.03
		8	0.04	0.04
		9	0.03	0.03
		10	0.04	0.04
		11	0.05	0.05
		12	0.10	0.13
		13	0.08	0.28
		14	0.13	0
		15	0.10	0
		16	0.08	0
Wind Speed Class		Frequency of Occurrence		
1		0.11		
2		0.34		
3		0.17		
4		0.24		
5		0.09		
6		0.05		

sectors 14 and 15 were distributed among sectors 12 and 13 in the proportions of 15 percent and 85 percent, respectively. The fraction of the winds from sector 16 was distributed among sectors 1 and 2 in proportions of 85 percent and 15 percent, respectively. Thus, the wind was not allowed to blow over the bluff to points downwind of it, but pollutant that was blown around the bluff could reach such stations. This altered frequency distribution, summarized by wind direction in Table 9, was used to calculate concentrations at receptor sites downwind of the bluff. The distribution is listed in Appendix I, in CDM-compatible format.

b. Western Kern County

The meteorological data used for Western Kern County were measured by SAI. Hourly wind direction, wind speed, ΔT , and stability as well as a joint-frequency distribution of wind speed, wind direction, and stability were obtained from SAI for each of two locations (described in Section IV-C-1) in western Kern County. One of the locations is meant to represent the meteorological regime of the northern portion of the oil fields, while the other is meant to represent the meteorological regime of the southern portion of the region. The frequency distributions were derived from a one-year sample of hourly data. A summary of the frequency of occurrence of each wind speed class, wind direction class, and stability class is given in Table 10. Listings of both distributions appear in Appendices J and K, in CDM-compatible format.

4. Meteorological Data for Short-Term Modeling

The modeling of short-term average SO_2 concentrations also was accomplished using CDM. The meteorological data required to generate the "false" frequency distributions, described in Section III, consists of hourly values of wind direction, wind speed, and atmospheric stability. The height of the mixed layer is also required for model calculations. The mixing height used in model calculations was taken from Holzworth.⁵ For 1- and 3-hour averages, an average winter morning height of 400 m was used because the worst-case concentrations generally occur in the

Table 10

JOINT-FREQUENCY DISTRIBUTIONS FOR THE NORTHERN
AND SOUTHERN SITES IN WESTERN KERN COUNTY

Stability Class	Frequency of Occurrence		Wind Speed Class	Frequency of Occurrence	
	North	South		North	South
1	0.02	0.02	1	0.27	0.30
2	0.06	0.06	2	0.49	0.48
3	0.00	0.00	3	0.18	0.18
4	0.31	0.31	4	0.05	0.04
5	0.08	0.08	5	0.01	0.00
6	0.53	0.53	6	0.00	0.00
Wind Direction Class		Frequency of Occurrence			
		North	South		
1		0.10	0.10		
2		0.07	0.06		
3		0.07	0.06		
4		0.05	0.04		
5		0.05	0.06		
6		0.04	0.03		
7		0.04	0.03		
8		0.04	0.03		
9		0.06	0.06		
10		0.06	0.10		
11		0.11	0.15		
12		0.08	0.08		
13		0.07	0.06		
14		0.05	0.03		
15		0.06	0.05		
16		0.07	0.07		

winter under the stable conditions characteristic of early morning. To be conservative, for 24-hour averages, the average winter morning height was assumed to persist all day.

The meteorological data that would typify the 1-, 3-, and 24-hour worst-case periods were identified using two different methods. One method makes use of an SRI computer program, WRSCASE, that was designed to use actual hourly meteorological data in calculating pollutant concentrations from up to five elevated sources, each with its own characteristics and emission rate, at as many as 320 receptor locations. The program uses the Gaussian point-source equation formulation. As many hours of meteorological data as are considered necessary to comprise a representative sample for a particular location are used in program calculations. WRSCASE determines the hourly concentration from all stacks at each receptor location that is downwind of the source, computes 24-hour average concentrations for all receptors, and chooses the 10 days on which the highest average concentrations occur.

The other method used to choose worst-case meteorology consists of calculating 3- and 24-hour average concentrations from the observed data and choosing the dates with the highest concentrations. Worst 1-hour times can be chosen directly from the data bases. Having identified the dates and times during which the highest concentrations were observed at the monitoring sites, the meteorological conditions under which the concentrations occurred can be examined.

When the same dates and times are chosen by both methods, the meteorological conditions at those times can be assumed with some confidence to be worst-case. In general, specific actual meteorological sequences were not used; rather, such sequences were idealized in the sense that some parameters were considered to be constant or nearly constant throughout the sequence, thus producing a somewhat more conservative sequence from a concentration standpoint. If even this conservative sequence does not produce concentrations in violation of the standards, it can be assumed that the standards are being met and will continue to be met. Also, the values of the meteorological variables were selected to coincide with the central values of CDM's wind speed and wind direction

classes, as these values are used by the model in computing concentrations.

a. Central Kern County

In central Kern County several dates and times were chosen as worst-case by both the WRSCASE program (using the characteristics of five typical generators as program input) and by using measured SO₂ concentrations. Since the SO₂ standards for short-term averaging periods may be violated once a year, the meteorology corresponding to the second worst concentration was deemed more appropriate as the guide in establishing the meteorological sequence to be used in model calculations. In addition the meteorological conditions for several days when WRSCASE predicted high concentrations and when measurements showed high values were examined to determine typical worst-case conditions. The examination revealed that the wind direction was roughly constant for no more than 14 hours on any day in the data sample and the wind for the remaining hours was at least 4 of the 16 wind direction sectors removed from the sector in which most of the roughly constant wind directions lay. For various averaging periods, certain wind directions emerged as those under which worst-case concentrations occur, and these directions are reflected in the choices of worst-case conditions described below.

Two different 24-hour meteorological sequences were used in computing 24-hour average concentrations. These sequences are listed in Table 11. The wind speed was assumed to be constant throughout the period; two different wind directions were used for each of the two cases. However, to be conservative, the wind was assumed to be constant for 16 hours of the day, and the direction for the other 8 hours was only four sectors removed from the sector containing the constant wind direction. Thus, the wind was allowed to blow from only two directions, while in reality the wind was never so constant. Stable conditions were assumed to persist during the nighttime hours, while neutral stability was assumed in the daytime. This stability distribution occurred on virtually all of the worst-case days examined.

Table 11

WORST-CASE METEOROLOGICAL CONDITIONS IN CENTRAL KERN
COUNTY FOR 1-, 3-, AND 24-HOUR AVERAGING PERIODS

Averaging Period (hours)	Wind Direction at Indicated Time (PST) (degrees)	Wind Speed at 150 ft (m/s)	Stability at Indicated Time (PST)
24	90 (0400-1100) (1600-2300)	4	4 (0500-2000) 6 (2100-0400)
	180 (1200-1500) (0000-0300)		
24*	270 (0400-1100) (1600-2300)	4	4 (0500-2000) 6 (2100-0400)
	180 (1200-1500) (0000-0300)		
3 and 1	67.5	1.5	4
3 and 1	67.5	1.5	6
3 and 1*	157.5	1.5	4
3 and 1	157.5	1.5	6
3 and 1	247.5	1.5	4
3 and 1	247.5	1.5	6
3 and 1	337.5	1.5	4
3 and 1	337.5	1.5	6

*Meteorological scenarios from which the highest concentrations
were computed.

classes, as these values are used by the model in computing concentrations.

a. Central Kern County

In central Kern County several dates and times were chosen as worst-case by both the WRSCASE program (using the characteristics of five typical generators as program input) and by using measured SO₂ concentrations. Since the SO₂ standards for short-term averaging periods may be violated once a year, the meteorology corresponding to the second worst concentration was deemed more appropriate as the guide in establishing the meteorological sequence to be used in model calculations. In addition the meteorological conditions for several days when WRSCASE predicted high concentrations and when measurements showed high values were examined to determine typical worst-case conditions. The examination revealed that the wind direction was roughly constant for no more than 14 hours on any day in the data sample and the wind for the remaining hours was at least 4 of the 16 wind direction sectors removed from the sector in which most of the roughly constant wind directions lay. For various averaging periods, certain wind directions emerged as those under which worst-case concentrations occur, and these directions are reflected in the choices of worst-case conditions described below.

Two different 24-hour meteorological sequences were used in computing 24-hour average concentrations. These sequences are listed in Table 11. The wind speed was assumed to be constant throughout the period; two different wind directions were used for each of the two cases. However, to be conservative, the wind was assumed to be constant for 16 hours of the day, and the direction for the other 8 hours was only four sectors removed from the sector containing the constant wind direction. Thus, the wind was allowed to blow from only two directions, while in reality the wind was never so constant. Stable conditions were assumed to persist during the nighttime hours, while neutral stability was assumed in the daytime. This stability distribution occurred on virtually all of the worst-case days examined.

Table 11

WORST-CASE METEOROLOGICAL CONDITIONS IN CENTRAL KERN
COUNTY FOR 1-, 3-, AND 24-HOUR AVERAGING PERIODS

Averaging Period (hours)	Wind Direction at Indicated Time (PST) (degrees)	Wind Speed at 150 ft (m/s)	Stability at Indicated Time (PST)
24	90 (0400-1100) (1600-2300)	4	4 (0500-2000) 6 (2100-0400)
	180 (1200-1500) (0000-0300)		
24*	270 (0400-1100) (1600-2300)	4	4 (0500-2000) 6 (2100-0400)
	180 (1200-1500) (0000-0300)		
3 and 1	67.5	1.5	4
3 and 1	67.5	1.5	6
3 and 1*	157.5	1.5	4
3 and 1	157.5	1.5	6
3 and 1	247.5	1.5	4
3 and 1	247.5	1.5	6
3 and 1	337.5	1.5	4
3 and 1	337.5	1.5	6

*Meteorological scenarios from which the highest concentrations
were computed.

Eight different 3-hour meteorological sequences were chosen. The wind direction, wind speed, and stability were held constant over the 3-hour period, but computations were made for all combinations of 4 wind directions and 2 stabilities. The conditions for which 1-hour averages were computed are identical to those for three hours, since in general the worst 1-hour concentrations were part of the worst 3-hour average concentrations. The 1- and 3-hour sequences appear in Table 11.

b. Western Kern County

The procedure described above for determining worst-case meteorology in central Kern County was applied to the data from the two meteorological and two air quality sites in western Kern County. As a result, three 24-hour meteorological sequences were chosen, each for a different but constant wind direction. In western Kern County the very conservative constant wind direction assumption could be made because emissions are less densely distributed than in central Kern County and the concentrations computed under this assumption do not approach the standard. For all three cases, the stability was assumed neutral in the daytime and very stable at night, and the wind speed was assumed constant at 1.47 m/s.

Six 3-hour sequences were chosen, with a constant wind direction, wind speed, and stability in each case. These cases consisted of all combinations of 2 wind directions and 3 stability classes. Wind speed was constant.

Nine sets of conditions were selected as worst-case 1-hour values. The nine cases consisted of all combinations of 3 wind directions and 3 stability classes, with a wind speed of 1.47 m/s.

The specific values of each variable used in model computations for western Kern County appear in Table 12 for 1-, 3-, and 24-hour periods.

Table 12

WORST-CASE METEOROLOGICAL CONDITIONS IN WESTERN KERN COUNTY
FOR 1-, 3-, AND 24-HOUR AVERAGING PERIODS

Averaging Period (hours)	Wind Direction (degrees)	Wind Speed (m/s)	Stability at Indicated Time (PST)
24*	67.5	1.47	4 (0500-2000) 6 (2100-0400)
24	112.5	1.47	4 (0500-2000) 6 (2100-0400)
24	247.5	1.47	4 (0500-2000) 6 (2100-0400)
3 and 1*	247.5	1.47	4
3 and 1	247.5	1.47	5
3 and 1	247.5	1.47	6
3 and 1	337.5	1.47	5
3 and 1	337.5	1.47	6
3 and 1	337.5	1.47	4
1	270	1.47	4
1	270	1.47	5
1	270	1.47	6

*Meteorological scenarios from which the highest concentrations were computed.

D. Ambient Air Quality Data

1. Description of Sites and Analysis of Suitability

a. Central Kern County Sites--General

The general locations of the Getty oil monitoring sites surrounding the Kern River Field are shown in Figure 16 in Section V-B-1. Six of the sites were obviously chosen to characterize concentrations along the perimeter of the major oil field area from its western edge through the southeastern side. This is the arc through which oil field emissions

must pass to reach the major populated areas. The seventh station, the Kern County Health Department site, is in a location that appears to be more representative of Bakersfield as a whole.

The station locations are such that the ambient concentrations arising from emissions within the oil field are not monitored when winds are from directions between about SE through West to NW. For all cases this represents about 40 percent of the hours. However, for those hours when atmospheric stability is classified as stable, or slightly stable, the frequency of winds from the above directions is about 20 percent. Thus, the monitoring sites are well situated to observe SO_2 concentrations arising from oil field emissions in about 80 percent of those cases when the highest concentrations are most likely.

Some of the individual sites in the Bakersfield area are discussed in the following paragraphs. The discussions have been guided by a recent report⁹ that presents siting criteria for the monitoring of SO_2 . These sites are all in the category of "General-Level, Neighborhood-Scale Stations," as defined by Ball and Anderson. For the purposes of this study the objective of the monitoring conducted at these stations is to define concentrations that are representative of areas with dimensions of the order of a few kilometers. Table 13 summarizes Ball's and Anderson's recommendations for the siting of such stations.

The recommendation for a windward location for rooftop inlets is based on a desire to avoid the effects of emissions from the building itself. This is not an important consideration in the Bakersfield area where SO_2 from space heating is not a problem. Similarly, the suggestion that the height be about 0.8 times the mean building height is to ensure reasonably uniform vertical profiles in an area of SO_2 sources. Since most of the stations in Bakersfield are reasonably well removed from local SO_2 sources, this criterion will not be particularly crucial.

No discussion of the types of instruments housed in the shelters at the sites will be given below because the shelters were locked and, thus, the instrumentation could not be examined.

Table 13

SITE CHARACTERISTICS AND INLET PLACEMENT CRITERIA
FOR NEIGHBORHOOD STATIONS

Station Location	Inlet Placement Criteria				Remarks
	Height Above Ground	Height Above Roof	Horizontal Clearance Beyond Structure	Horizontal of Inlet Placement	
Rooftop	A little less than the mean height of buildings in neighborhood or lower ($\leq 0.8H^*$) [†]	Between 1-2 m and away from dirty/dusty areas	Not Applicable (N.A.)	Locate inlet on windward side of building relative to the prevailing winter wind direction, particularly if bluff side of building is toward prevailing direction.	No SO ₂ source on roof of building.
Intermediate Height on Building	Same as Rooftop	N.A.	1 to 2 meters	Same as Rooftop	No SO ₂ source on roof of building.
Trailer	3 to 5 meters	1 to 2 meters	Not critical	Not critical	If possible, avoid parking lots and lots around which are buildings with stacks, particularly if nearest building upwind has a large stack. If located in park, avoid sites under thick forest canopy.

* $\bar{H}$ = mean height of buildings in neighborhood (or in middle-scale area of interest for middle-scale stations or in zone of maximum emission densities for emergency episode stations).

[†]In suburban areas choose a building of low height--preferably one-story.

Source: Ball and Anderson, 1977

b. Kern County Environmental Health Services Site

The Kern County Environmental Health Services site is located at that agency's building on the corner of Virginia and Flower Streets. The inlet is about 75 m northeast of the intersection at roof level of the single-story building. The inlet is at the edge of the roof near an interior courtyard and the inlet line runs about 6 to 8 m to the instrument housing.

The site is a generally residential neighborhood, about 0.5 km west of the county hospital and about 1 km southwest of a freeway (Highway 178). This appears to be a generally good location. An inlet location somewhat more removed from the roof would probably be better, but considering the general lack of SO₂ sources in the vicinity, it should pose no problem.

c. Kern Bluff Site

The Kern Bluff site is the westernmost of the Bakersfield monitors. It is located at an elevation of about 220 m (MSL) in an open, unpaved area. The site is about 100 m northeast of a very lightly traveled two-lane road to the Kern Bluff oil field. The nearest boundary of this small field is less than 0.5 km to the southeast and might interfere with representative observations when winds are from that quadrant. The site is about 0.75 km southeast of a major roadway, Alfred Harrell Highway, which is at the foot of the bluff, at an elevation about 60 m lower than the site.

The instruments are located in a freestanding shelter with a well-exposed inlet about 2 m high. With the possible exception of interferences from the nearby Kern Bluff oil field, it should provide readings representative of the surrounding area.

d. Kern County Communications Center Site

The instruments at this site are housed in a trailer at the Kern County Communications Center. The immediate surrounding area is fenced and similar to a corporation yard. The inlet height is about 3 m, at

the south side of the trailer, about 30 cm above roof level. Several other pollutants are also measured at this site. A meteorological tower supports an anemometer about 10 m above the surface.

The location is about 250 m east of the intersection of Mt. Vernon Ave. and Panorama Dr., on the south side of Panorama. It is set back from the street about 15 m, with a fence about 2 m high between it and the street. The location is at an altitude of about 250 m (MSL), about 300 m southeast of a 90 m high bluff. There are residential areas to the north (between the site and the bluff), east and south. Bakersfield City College is to the west.

e. Panorama West Site

The Panorama West site could not be located. It appears to be at the northern edge of a residential area made up of relatively large homes on large lots. The area is at the top of the bluff overlooking the Kern Canal and Kern River. In this area, the bluff is about 45 m high.

f. Manor Drive Site

This site is at an altitude of about 140 m (MSL) in a storage area. It is about 250 m east of Manor Drive and about 0.5 km north of a refinery.

The instrument is located in a freestanding box with an inlet at about 2 m. The immediate area is unpaved and without ground cover. The site may be too close to the refinery to be very representative of the surrounding area, especially during periods of south winds.

g. Kern River Site

The Kern River site (Producers 105) is located at the edge of the Kern River oil field at an altitude of about 190 m (MSL). The site is about 10 m east of a dirt oil field road. The immediate surroundings are reasonably barren. The instruments are mounted in a box with the inlet at about 2 m above the surface.

h. Kern Front Site

The Kern Front site is a corporation yard of the Getty Oil Company. The yard is unpaved. The box mounted instrument has its inlet at a height of about 2 m. The location is at the eastern edge of the Kern River field. The site elevation is about 215 m (MSL).

i. Suitability of Central Kern County Site Locations

In general, the SO₂ monitors around Bakersfield are well sited for the purpose for which the data are being used. However, several are closer to SO₂ sources than is desirable.

j. Western Kern County Sites

Only one of the sites in western Kern County, the monitor near Fellows, was visited, although the general area in which the other is located was inspected. Both air-quality monitoring sites in western Kern County are near Highway 33, which runs generally northwest--southeast between McKittrick and Taft. Locations near this roadway provide measurements that represent conditions in the region of major public access. One of the sites, in Taft, provides a measure of public exposure in the largest population center of the area. The sites appear to be representative of general conditions on the west side.

2. Description of Data

a. Central Kern County

The hourly SO₂ data used in this study to calibrate the central Kern County SO₂ concentrations computed by the models were measured by Getty Oil Company. Data from seven sites, in and around Bakersfield, were used to determine calibration factors. The locations of the seven sites are shown in Figure 16, which appears in Section V-B-1. For one location, the Kern River (Producers 105) site, data were available for a two-year period. For four of the sites, data were obtained for a 15-month period. The other two sites have been in operation for a shorter period of time; ten months of data were available for the first

site and nine months of data for the second. The contract for this study did not call for, nor was there performed, a quality assurance check on the air quality data.

The dates for which SO₂ data were obtained for each monitoring station are listed in Table 14. One year of hourly data for the Kern River site and three months of hourly data for the Manor, Panorama, Kern County Health Department, and Kern County Community Center sites were obtained from Aerovironment, Inc., with the permission of Getty Oil Company. This data was on magnetic tape. The remaining data listed in Table 14 (for most stations, one year of data) were obtained from the Kern County Air Pollution Control District (KCAPCD). The data were written on forms supplied to the KCAPCD by Getty. The data have been coded and punched on cards, and a file containing the data was created on our computer.

A communication dated 10 November 1977 from Getty to the KCAPCD was forwarded to SRI by EPA. That communication indicated that the SO₂ values from the seven Bakersfield area monitors for the months January through June, 1977 that had been supplied to the KCAPCD were incorrect.

Table 14

SO₂ DATA AVAILABILITY--SEVEN MONITORING LOCATIONS
IN CENTRAL KERN COUNTY

Site	Data Period		
	On Tape	On Forms	Total
Kern River	Jul 75 - Jun 76	Jul 76 - Jun 77	Jul 75 - Jun 77
Manor	Apr 76 - Jun 76	Jul 76 - Jun 77	Apr 76 - Jun 77
Panorama	Apr 76 - Jun 76	Jul 76 - Jun 77	Apr 76 - Jun 77
Kern Co. Health Dept.	Apr 76 - May 76	Jul 76 - Jun 77	Apr 76 - May 76 Jul 76 - Jun 77
Kern Co. Community Center	Apr 76 - Jun 76	Jul 76 - Jun 77	Apr 76 - Jun 77
Kern Front	---	Sep 76 - Jun 77	Sep 76 - Jun 77
Kern Bluff	---	Oct 76 - Jun 77	Oct 76 - Jun 77

An equation was given that could correct the values. However, the information available to SRI was insufficient to correct each hourly SO₂ value. Therefore, the following procedure was applied to correct the data. First, the ratio of the correct 1-hour maximum to the incorrect 1-hour maximum was computed for each day. Then, for each hour of a day, the ratio appropriate to that day was multiplied by the incorrect SO₂ value. The results were "corrected" hourly SO₂ concentrations.

Examination of the SO₂ data for central Kern County revealed a number of inconsistencies. A discussion of these inconsistencies follows. The months of August and September 1976 contain several periods, for the various monitoring sites, for which zero SO₂ concentration values were reported. In some cases, four of the five stations operational at that time report zero concentration. In other cases, a period of zero concentrations at one station is immediately followed by a period of zero concentration at another station. Most of the periods for which zero concentrations are reported begin at 0100 hours and end at 2400 hours. Often the first nonzero concentration reported after one of the zero periods is as high as 50 to 90 ppb; the same is true of the last concentration reported before the zero period begins.

For some of the zero concentration periods, no wind direction exists that could explain a zero value at one monitoring location and a nonzero value as high as 50 to 80 ppb at a nearby station. For some of the periods for which zero concentrations were reported, the actual wind directions and speeds that occurred were checked. The actual meteorological conditions were not atypical and in fact were conditions under which a nonzero concentration would be expected.

During other months of the data sample, several hours of zero values did occasionally occur. However, in all cases, the zero concentrations did not persist for 24 hours, nor were the beginning and ending times of the period 0100 or 2400 hours. In addition, for most days a -1 value (denoting a span check or missing data) was reported for at least one hour of the day. During the zero concentration periods, no -1 values were reported.

The points discussed above suggest that the "zero" values were actually missing data. Thus, when annual average concentrations were computed, two averages were computed, one using the zero values, and one for which those days were denoted as missing. (See discussion in Section V-A-1.) For calibration purposes, the suspect dates, listed in Table 15, were assumed to be missing data.

Table 15
REPORTED ZERO SO₂ CONCENTRATIONS OF 24-HOUR DURATION
AT SIX BAKERSFIELD AREA SITES

Site	Dates with Zero Concentrations
Kern River	19 Aug 76 to 28 Aug 76, 30 Aug 76, 5 Sep 76, 13 Sep 76, 17 Sep 76 to 23 Sep 76
Manor	20 Aug 76 to 26 Aug 76, 24 Sep 76 to 28 Sep 76
Panorama	13 Aug 76 to 16 Aug 76, 20 Aug 76 to 23 Aug 76
Kern Co. Health Dept.	9 Aug 76 to 12 Aug 76, 20 Aug 76 to 23 Aug 76
Kern Co. Community Center	21 Aug 76, 11 Sep 76 to 13 Sep 76
Kern Front	28 Sep 76 to 29 Sep 76

b. Western Kern County

The hourly SO₂ data used in this study to calibrate model-computed concentrations in Western Kern County were measured by and obtained from SAI. Data were available for two locations in the Westside oil fields. One of the monitoring sites is located in the northern portion of the fields and is shown in Figure 20, in Section V-B-2. The other site is located in the southern portion of the oil fields and is shown in Figure 22, also in Section V-B-2.

Both sites have been in operation since early in 1976. The data sample obtained from SAI was for a one-year period, 1 May 1976 through 30 April 1977.

V MODELING OF LONG-TERM AVERAGE CONCENTRATIONS

A. Model Calibration

The model was calibrated using the available SO₂ data, as described in Section IV-D. The annual average concentration was computed by SRI from measured hourly concentrations for each monitoring site. The determination of the calibration factors through linear regression for both central and western Kern County is discussed below.

1. Central Kern County

In Section IV-D-2 we noted the inconsistencies discovered in the central Kern County SO₂ data. A certain amount of uncertainty is associated with the computation of calibration factors from such data. Therefore, all of the computations of annual average SO₂ concentrations were made twice, first using the data as reported, and then removing the questionable zero values and treating those hours as if missing data had been reported. The results of the annual average SO₂ concentration computations for all seven monitoring sites are listed in Table 16. The different types of averages computed for each site are discussed below.

For the Kern River site, data covering two years were available. To examine the change in the annual average concentration, the average over each year of the data, as well as over both years, was computed. The variation among the annual averages computed using various data periods varies by less than 6 percent. The value used for calibration purposes was computed from the 2-year data sample and with the questionable zero values treated as missing data.

Data for the Manor, Panorama, Kern County Health Department, and Kern County Community Center sites cover a 15-month period. Four different annual average concentrations were computed for each site. First an average concentration over the 15-month period was computed from the data

Table 16
ANNUAL AVERAGE SO₂ CONCENTRATIONS FOR BAKERSFIELD SITES

Averaging Period	Status of Questionable Data	Kern River		Manor		Panorama		Kern Co. Health Department		Kern Co. Comm. Center		Kern Front		Kern Bluff	
		Average Conc. (ppb)	No. of Hours	Average Conc. (ppb)	No. of Hours	Average Conc. (ppb)	No. of Hours	Average Conc. (ppb)	No. of Hours	Average Conc. (ppb)	No. of Hours	Average Conc. (ppb)	No. of Hours	Average Conc. (ppb)	No. of Hours
7/1/75 - 6/30/76	none	27.9	7063												
7/1/76 - 6/30/77	included	28.0	8324												
7/1/76 - 6/30/77	not included	29.6	7864												
7/1/75 - 6/30/77	included	27.9	15387												
7/1/75 - 6/30/77	not included	28.8*	14927												
4/1/76 - 6/30/77	included			19.5	9873	13.4	9409	10.5	10029	18.6	9468				
4/1/76 - 6/30/77	not included			20.1	9596	13.7	9221	10.7	9843	18.7	9376				
4/1/76 - 6/30/77†	included			20.5	8265	13.5	8189	10.7	8160	18.6	8329				
4/1/76 - 6/30/77†	not included			21.2*	7988	13.8*	8001	10.9*	7974	18.8*	8237				
9/22/76 - 6/30/77	included											29.0	6276		
9/22/76 - 6/30/77	not included											29.3*	6230		
10/16/76- 6/30/77	none													14.1*	5779

* Average concentrations used to compute calibration factors.

† Hourly concentrations for months 4, 5, and 6 for 1976 and 1977 were averaged together, and the resulting hourly averages were used in the annual average computations.

base as reported. Then another average concentration was computed assuming the questionable zero data were actually missing data. The other computations consisted of averaging the 1976 and 1977 concentrations of each hour during the months of April, May, and June, and then using those averages along with the remainder of the data sample to compute the annual average. This was done both with and without the questionable zero data. The intent was not to allow the annual average to be unduly influenced by the presence of data from two years in the spring months and only one year for the remainder of the year. It was by this method of computation (with the questionable zero values treated as missing data) that the annual average concentration used to calculate calibration coefficients was determined for each of the four sites listed above.

Annual averages for the Kern Front site were computed with and without the questionable data. The value computed without the questionable data was used for calibration purposes. None of the data from the Kern Bluff site appeared inconsistent, so a simple average of the nine months of data that were available was taken.

To compute the calibration factors, a linear regression routine was used to fit the annual average concentration computed with CDM for the existing source configuration to the observed annual average SO_2 concentration at each site. The calibration factors are computed to fit the following equation:

$$X_{\text{obs.}} = mX_{\text{cal.}} + b$$

where $X_{\text{obs.}}$ = observed SO_2 concentration (ppb)

$X_{\text{cal.}}$ = calculated SO_2 concentration (ppb)

m = slope

b = y-intercept

The slope and y-intercept computed for all seven sites (Case 1) are listed in Table 17.

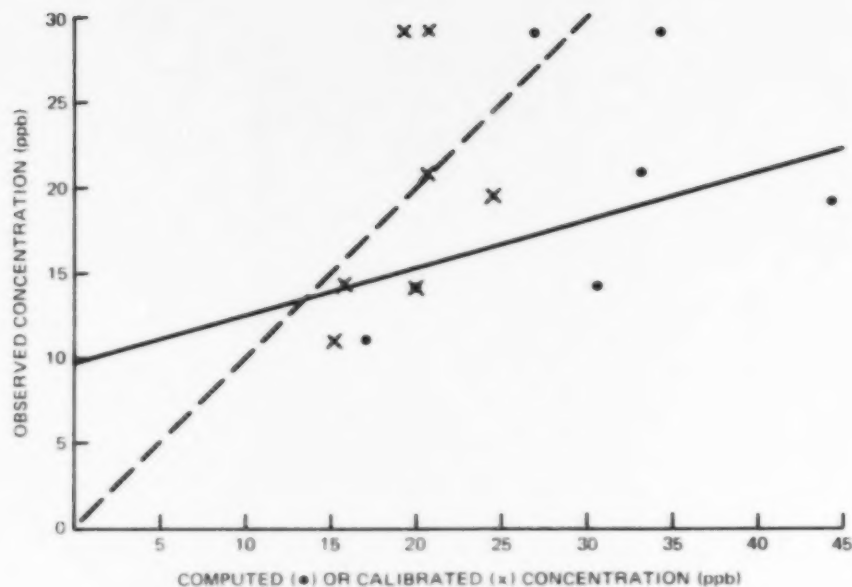
Since the topography of central Kern County is not regular, an attempt was made to simulate the effects of the irregularity. An altered meteorological frequency distribution, as described in Section IV-C-3-a, was used to compute SO_2 concentrations at the three sites located downwind of the bluff. These concentrations were fitted to the observed concentrations at the three sites (Case 2a), while the concentrations at the four remaining sites, computed with the original wind field, were fitted to the observed concentrations (Case 2b). The resulting two sets of calibration factors appear in Table 17.

Scatter diagrams of the observed compared with computed and calibrated concentrations for all seven sites taken together (Case 1) and for the sites taken as described above (Cases 2a and 2b) are shown in Figure 15. The solid line in each part of the diagram is a best fit to the observed and computed concentrations and is described by the regression constants listed in Table 17. The dashed line is a best fit to the observed and calibrated concentrations.

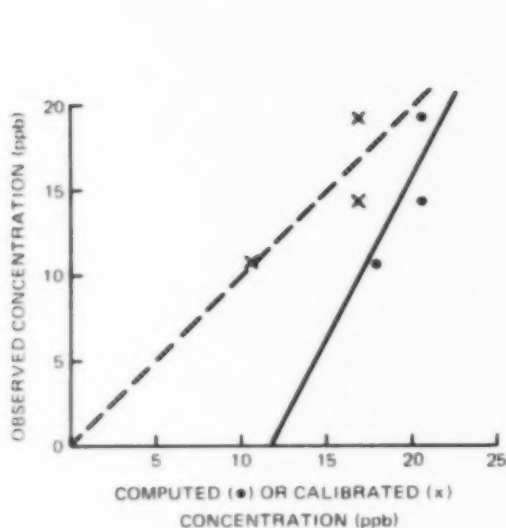
Table 17
CALIBRATION FACTORS FOR CENTRAL KERN COUNTY

Case	Calibration Constants	
	m	b
1	0.3361	9.680
2a	1.833	-22.0
2b	0.732	2.388

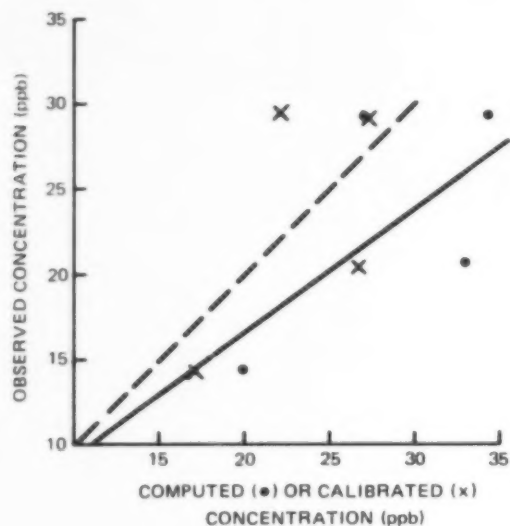
The observed, computed, and calibrated annual average SO_2 concentrations for the existing source configuration at the seven central Kern County monitoring sites are listed in Table 18.



(a) ORIGINAL FREQUENCY DISTRIBUTION AT ALL SITES (CASE 1)



(b) ALTERED FREQUENCY DISTRIBUTION AT THREE SITES (CASE 2a)



(c) ORIGINAL FREQUENCY DISTRIBUTION AT FOUR SITES (CASE 2b)

FIGURE 15 OBSERVED COMPARED WITH COMPUTED AND CALIBRATED CONCENTRATIONS.

Table 18
OBSERVED, COMPUTED, AND CALIBRATED ANNUAL AVERAGE SO₂ CONCENTRATIONS
AT THE BAKERSFIELD SITES

Site	Observed Concentration (ppb)	Existing Computed Concentration (ppb)		Existing Calibrated Concentration (ppb)		
		Original Winds	Altered Winds	Case 1	Case 2a	Case 2b
Kern River	29	27	--	19	--	22
Manor	21	33	--	21	--	27
Panorama	14	20	--	16	--	17
Kern Co. Health Dept.	11	17	18	15	11	--
Kern Co. Comm. Center	19	44	21	24	17	--
Kern Front	29	34	--	21	--	27
Kern Bluff	14	31	21	20	17	--

2. Western Kern County

Sulfur dioxide concentrations are measured at two locations in western Kern County. Hence, calibration factors were derived from measured and calculated annual average concentrations for only two locations.

The data bases for both sites were comprised of hourly SO_2 values for a one-year period. The annual average concentration computed from the observed data was 6 ppb at each site. Computation of annual average concentrations using CDM (see discussion of model calculations in Section V-B-2) produced identical values of 12 ppb at the locations of both measurement sites. The calibration factors that result from a linear fit of calculated to observed concentrations are a slope of 0.5 and a y-intercept of zero.

B. Existing Case Results

1. Central Kern County

The CDM model was used to compute the SO_2 concentrations in central Kern County resulting from crude oil-fired steam generators and other SO_2 sources. The input data, other than the source data and the frequency distribution, that were used in model runs are listed in Appendix L. Other model input data included the generator source inventory as it exists at the present time (listed in Appendix A) as well as the non-generator source inventory (listed in Appendix G). The original meteorological frequency distribution (listed in Appendix H) derived from the Getty meteorological data was used to compute the SO_2 concentrations shown in Figure 16. These concentrations are uncalibrated; both the measured and calculated concentrations are shown in the figure for each of the seven Bakersfield area SO_2 monitoring sites. The maximum calculated concentration was 78 ppb.

Figure 17 shows the SO_2 distribution when the calculated concentrations shown in Figure 16 are calibrated according to the procedures outlined in Section V-A-1. These values were computed using the calibration factors derived for all seven sites, from concentrations computed with the original wind field. The maximum calibrated SO_2 value was 36 ppb.

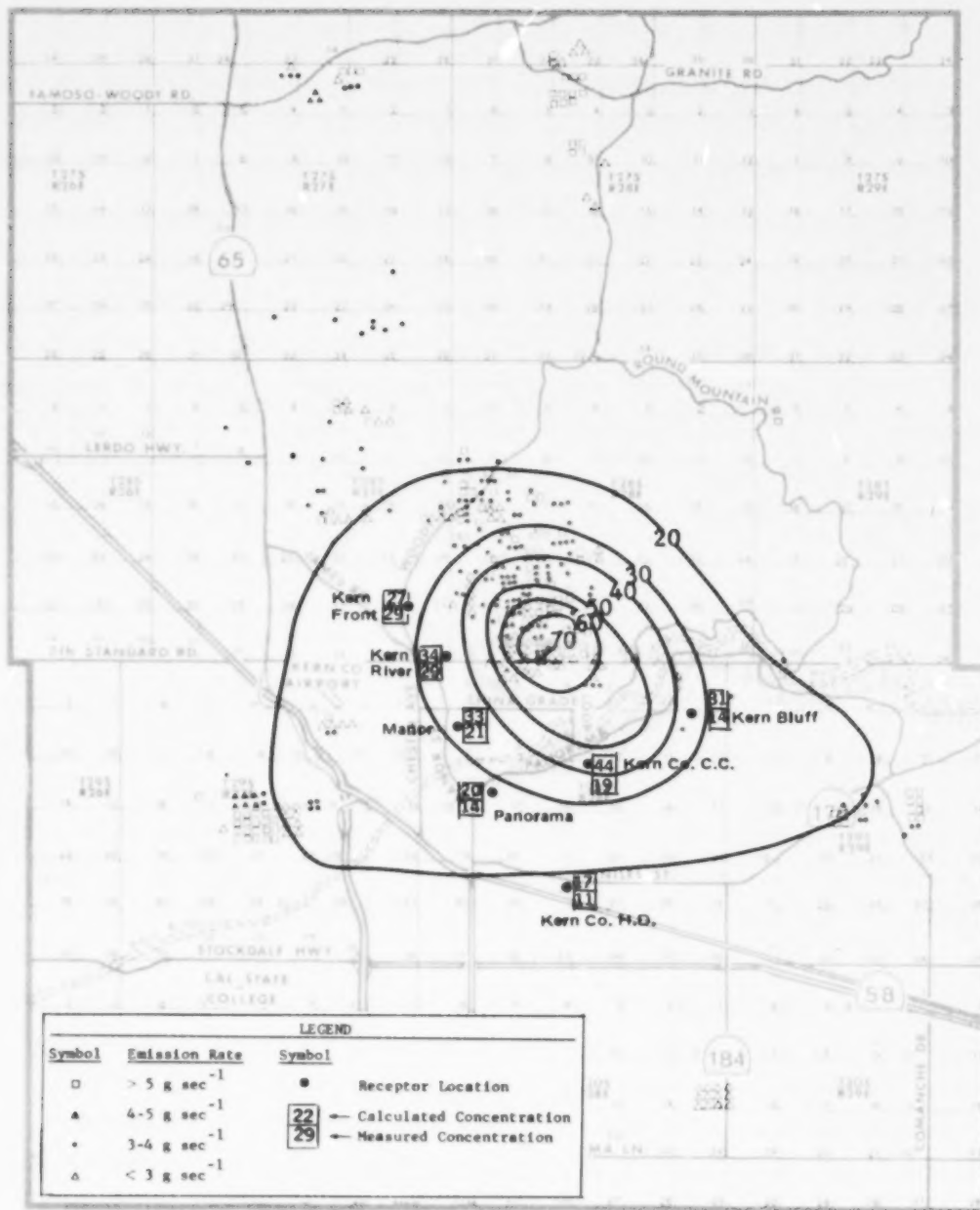


FIGURE 16 UNCALIBRATED ANNUAL AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE KERN RIVER OIL FIELDS (EXISTING SOURCES, ORIGINAL WIND FIELD)

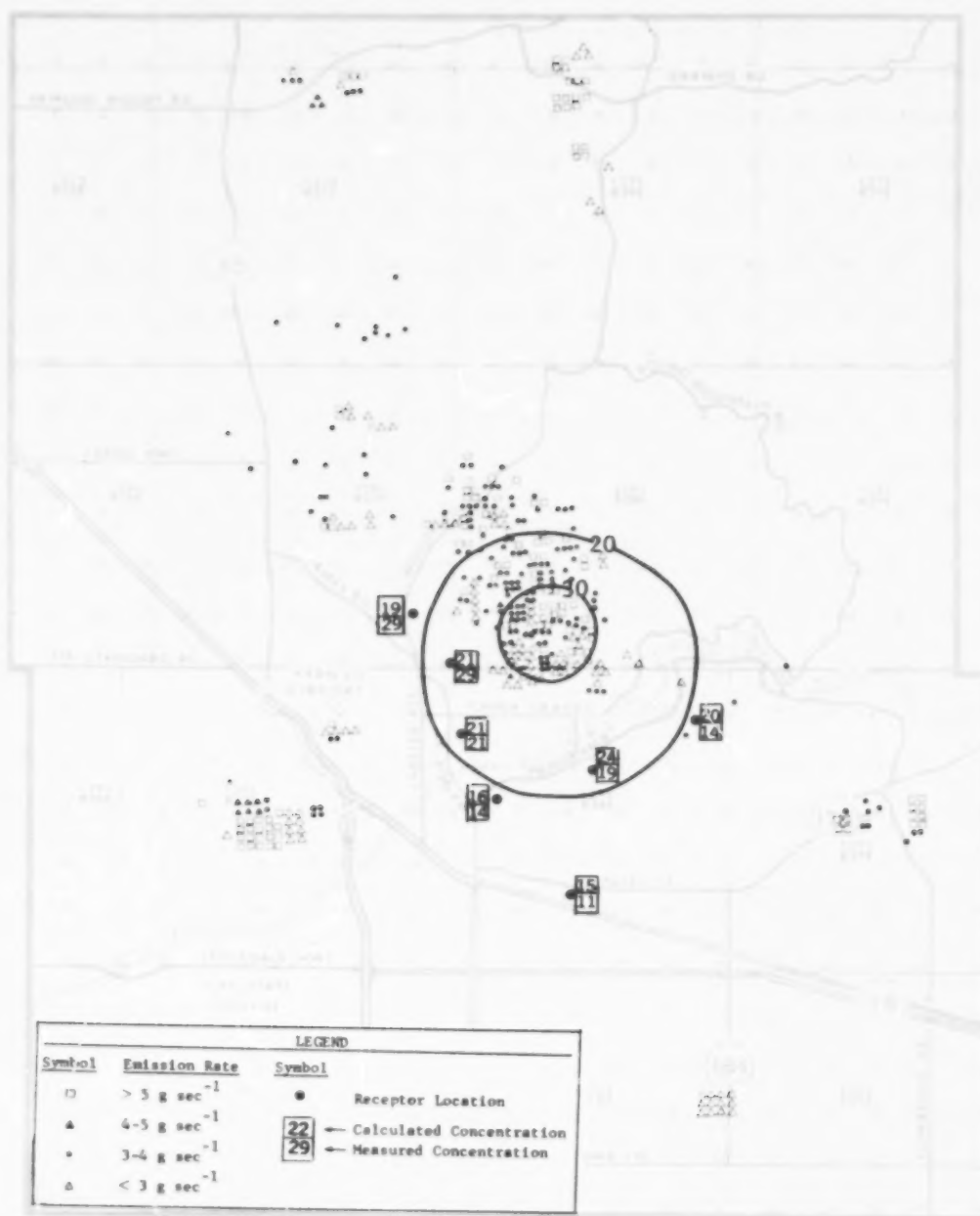


FIGURE 17 CALIBRATED ANNUAL AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE KERN RIVER OIL FIELDS (EXISTING SOURCES, ORIGINAL WIND FIELD)

As is evident from Figure 17, an area of about 8 km^2 shows SO_2 concentrations in excess of 30 ppb when the original wind field is used to compute concentration. In Table 1, the federal primary standard for the annual average SO_2 concentration is 30 ppb. Therefore, using the method outlined above, one finds that the area near Oildale exceeds the standard.

Because the dispersion in the Bakersfield area is complicated by the present of the bluff, another method of computing concentration was devised to try to produce a better fit to the measured concentrations. An altered joint-frequency distribution (listed in Appendix I) of wind speed, wind direction, and stability was produced according to the method presented in Section IV-C-3-a. This frequency distribution was used to compute SO_2 concentrations downwind of the bluff. The box formed by the dashed lines in Figure 18 delineates the area downwind of the bluff; concentrations for all locations within the box were computed using the altered wind field. Concentrations outside the box were computed with the original wind field. The resulting SO_2 pattern is illustrated in Figure 18. The maximum concentration was 78 ppb.

To calibrate these concentrations, two separate sets of calibration factors were derived, as discussed in Section V-A-1. One set of factors was applied outside of the box and another was applied inside the box. The results are shown in Figure 19. The concentrations calibrated in this way are a much better fit to the measured concentrations than were the calibrated concentrations computed with the original wind field.

Using this method to determine concentration, the 30 ppb contour, within which the standard is exceeded, has increased considerably to cover an area of about 40 km^2 . The maximum computed (calibrated) concentration was 58 ppb.

2. Western Kern County

The oil fields in western Kern County are located along a roughly NNW to SSE line about 70 km long. Because of the considerable spread of the oil field locations, meteorological data were gathered at two sites,

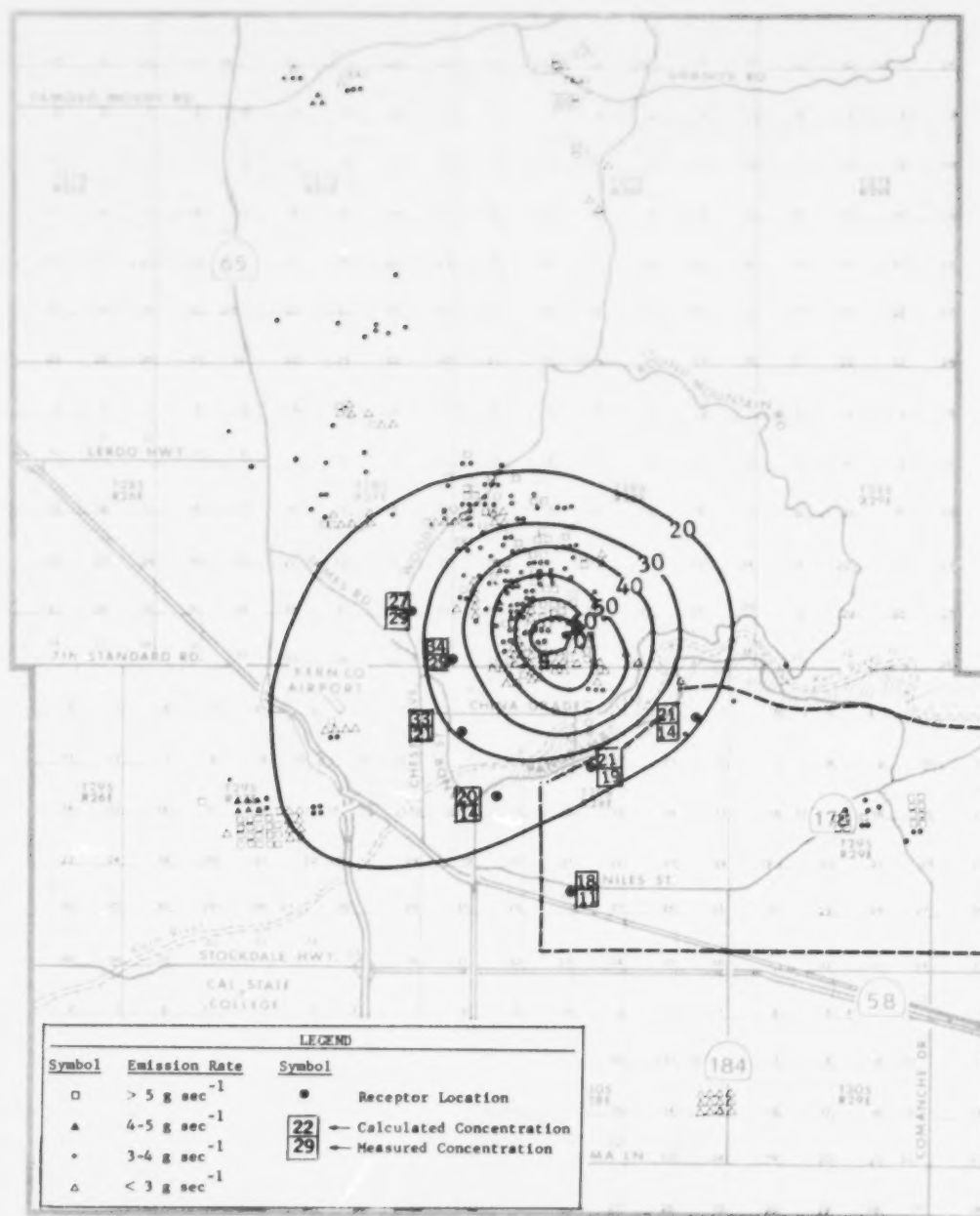


FIGURE 18 UNCALIBRATED ANNUAL AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE KERN RIVER OIL FIELDS (EXISTING SOURCES, ORIGINAL WIND FIELD OUTSIDE BOX, ALTERED WIND FIELD WITHIN BOX)

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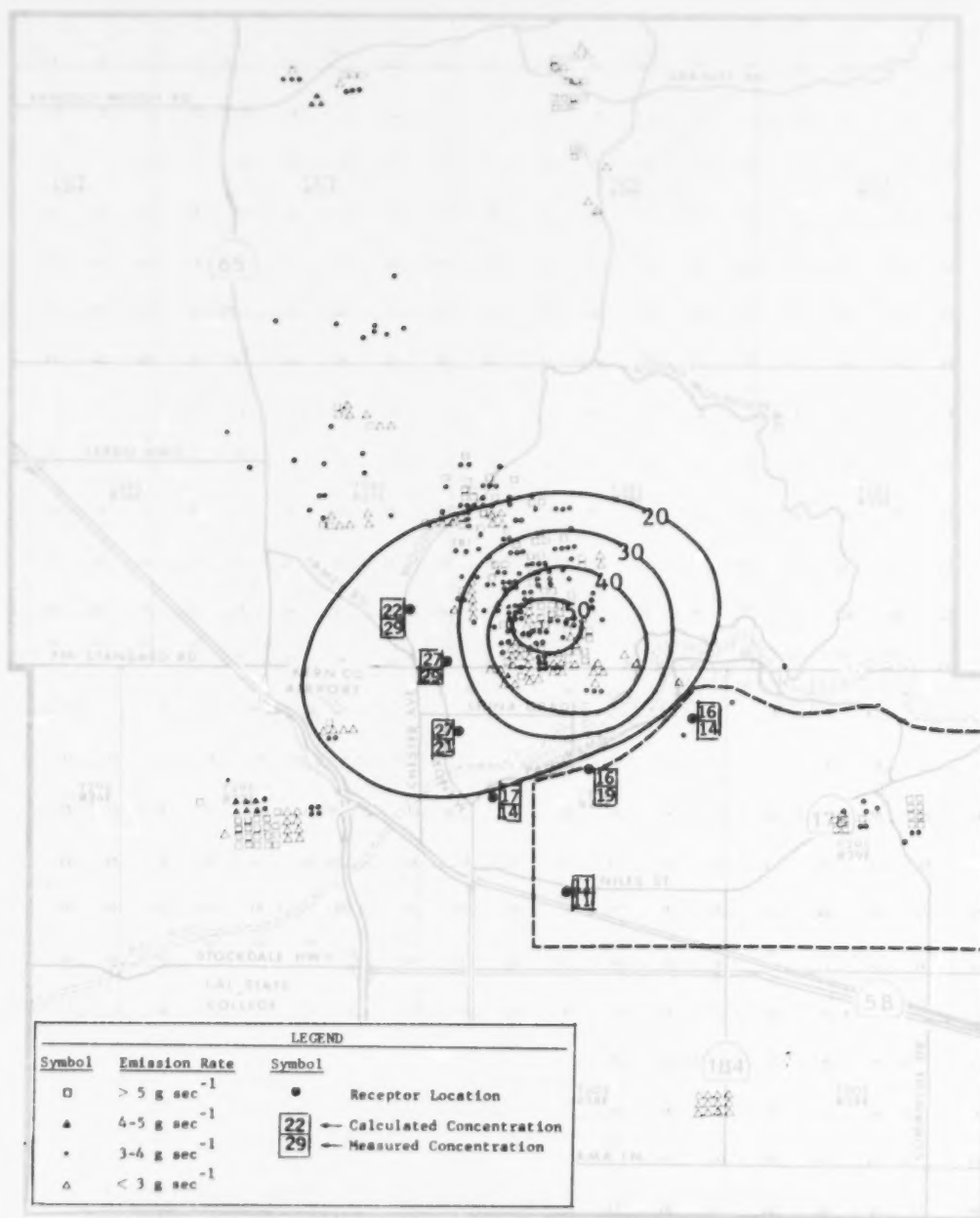


FIGURE 19 CALIBRATED ANNUAL AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE KERN RIVER OIL FIELDS (EXISTING SOURCES, ORIGINAL WIND FIELD OUTSIDE BOX, ALTERED WIND FIELD WITHIN BOX)

one located in the northern portion and the other in the southern portion of the fields. A joint-frequency distribution was generated from each site for use as model input data. These distributions are listed in Appendices J and K. The source inventory was also divided into two parts; the existing northern sources are listed in Appendix C and the existing southern sources are listed in Appendix E.

The CDM was used to compute SO_2 concentrations in the western Kern County oil fields using the method presented below. Concentrations at all receptors resulting from sources located in the northern portion of the study area were computed using the north meteorological frequency distribution. Concentrations at all receptors resulting from sources located in the southern portion of the study area were computed using the south meteorological frequency distribution. Then, for each receptor, the concentrations resulting from the northern and from the southern sources are summed to give the total concentration at the receptor.

In Section IV-B-1 the source locations in western Kern County were presented on five maps. The SO_2 concentration patterns arising from the existing and future case source configurations will be presented on those same maps. If no concentration on a map exceeded 5 ppb, concentration isopleths for that map will not be presented.

The uncalibrated annual average SO_2 concentrations in the Belridge-McKittrick area are shown in Figure 20. Figure 21 shows the calibrated concentrations in the same area. The maximum uncalibrated concentration was 24 ppb; calibrated, it was 12 ppb.

Figure 22 illustrates the uncalibrated SO_2 concentrations in the Fellows-Taft area and Figure 23 gives the calibrated concentrations for the same location. The maximum uncalibrated and calibrated concentrations were 42 ppb and 21 ppb, respectively.

In the southwestern Kern County area, uncalibrated SO_2 concentrations are low, as shown in Figure 24. When calibrated, all concentrations in that area were below 5 ppb. Annual average SO_2 concentrations at all other locations in western Kern County were also below 5 ppb.

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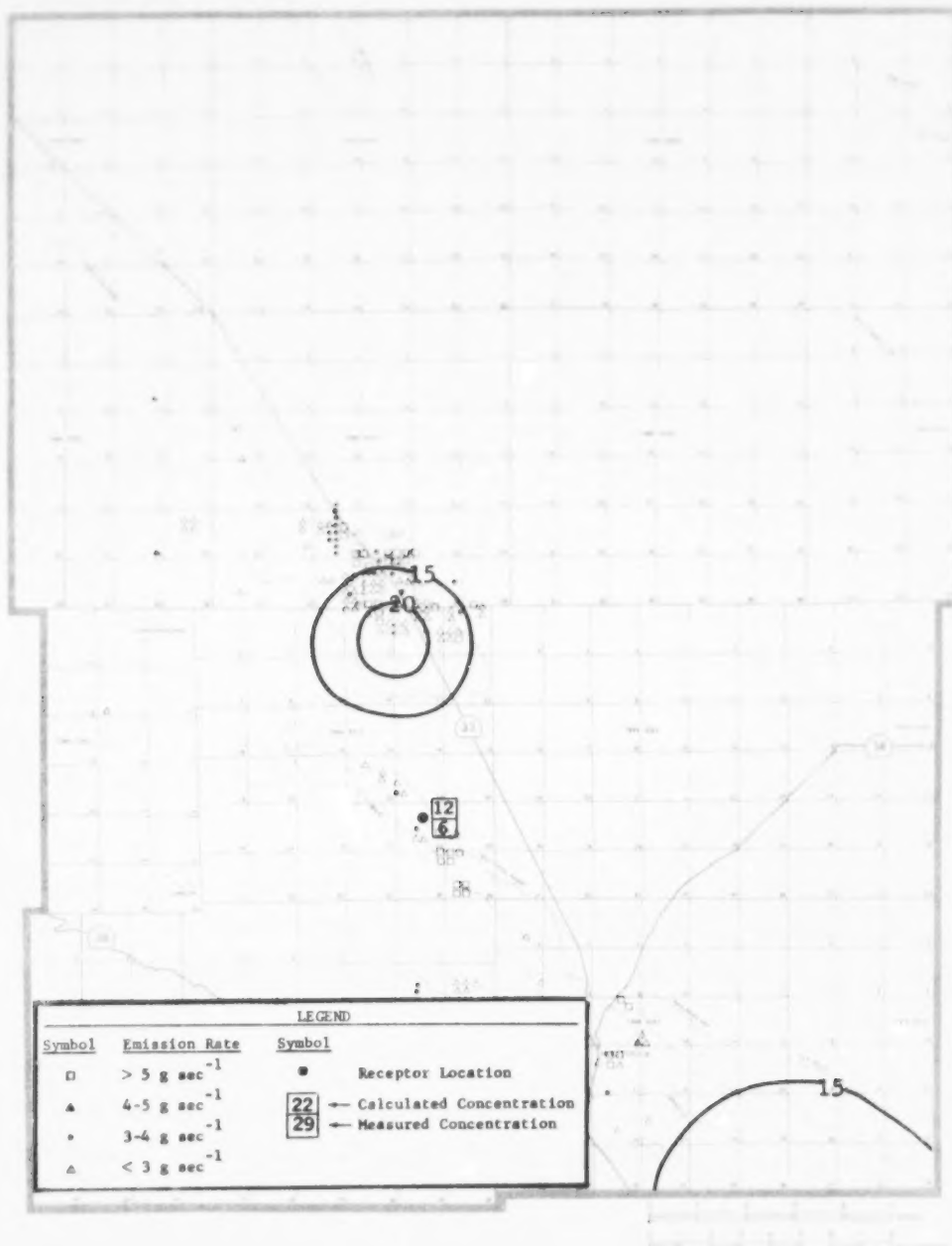


FIGURE 20 UNCALIBRATED ANNUAL AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE BELRIDGE-MCKITTRICK AREA (EXISTING SOURCES)

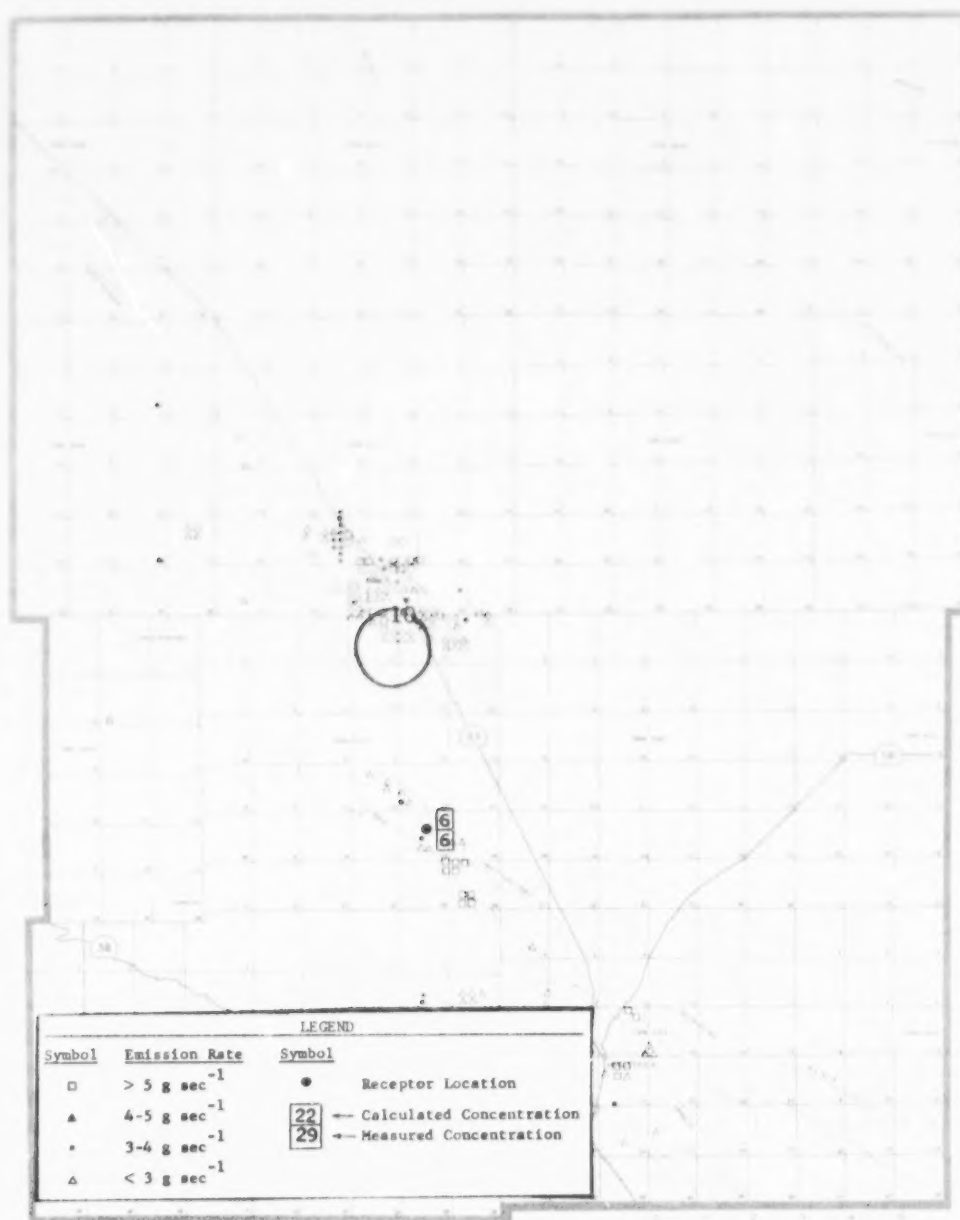


FIGURE 21 CALIBRATED ANNUAL AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE BELRIDGE MCKITTRICK AREA (EXISTING SOURCES)

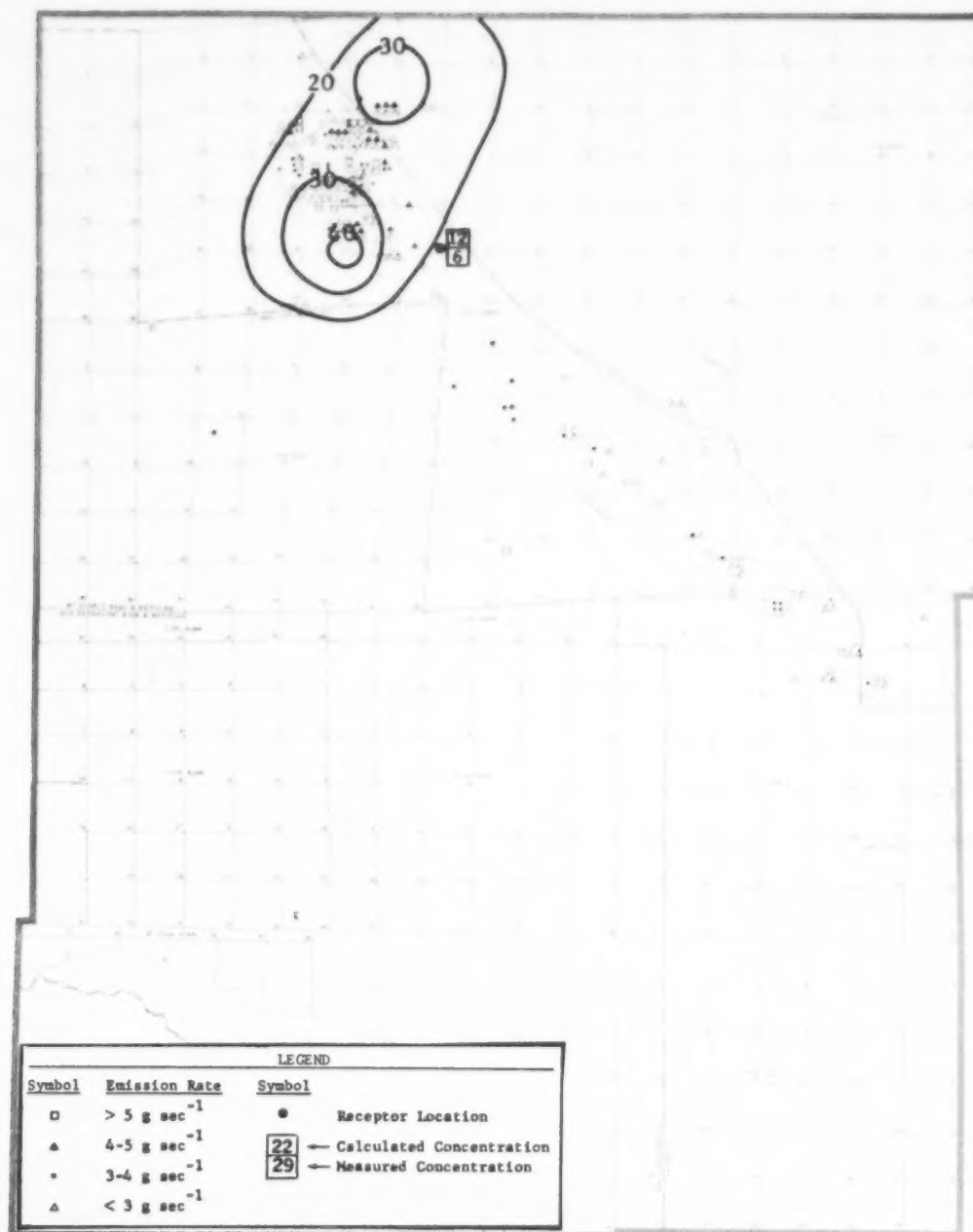


FIGURE 22 UNCALIBRATED ANNUAL AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE FELLOWS-TAFT AREA (EXISTING SOURCES)

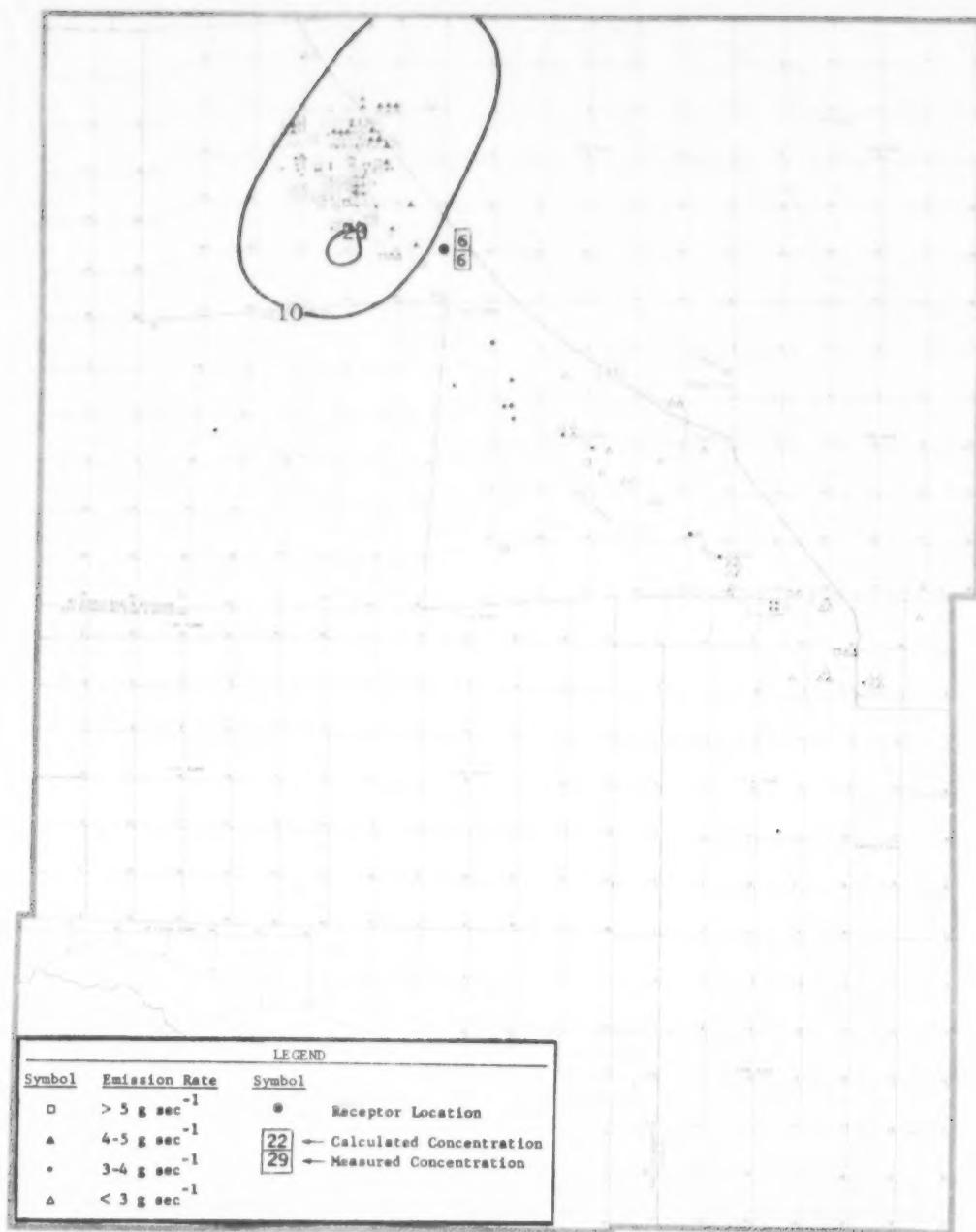


FIGURE 23 CALIBRATED ANNUAL AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE FELLOWS-TAFT AREA (EXISTING SOURCES)

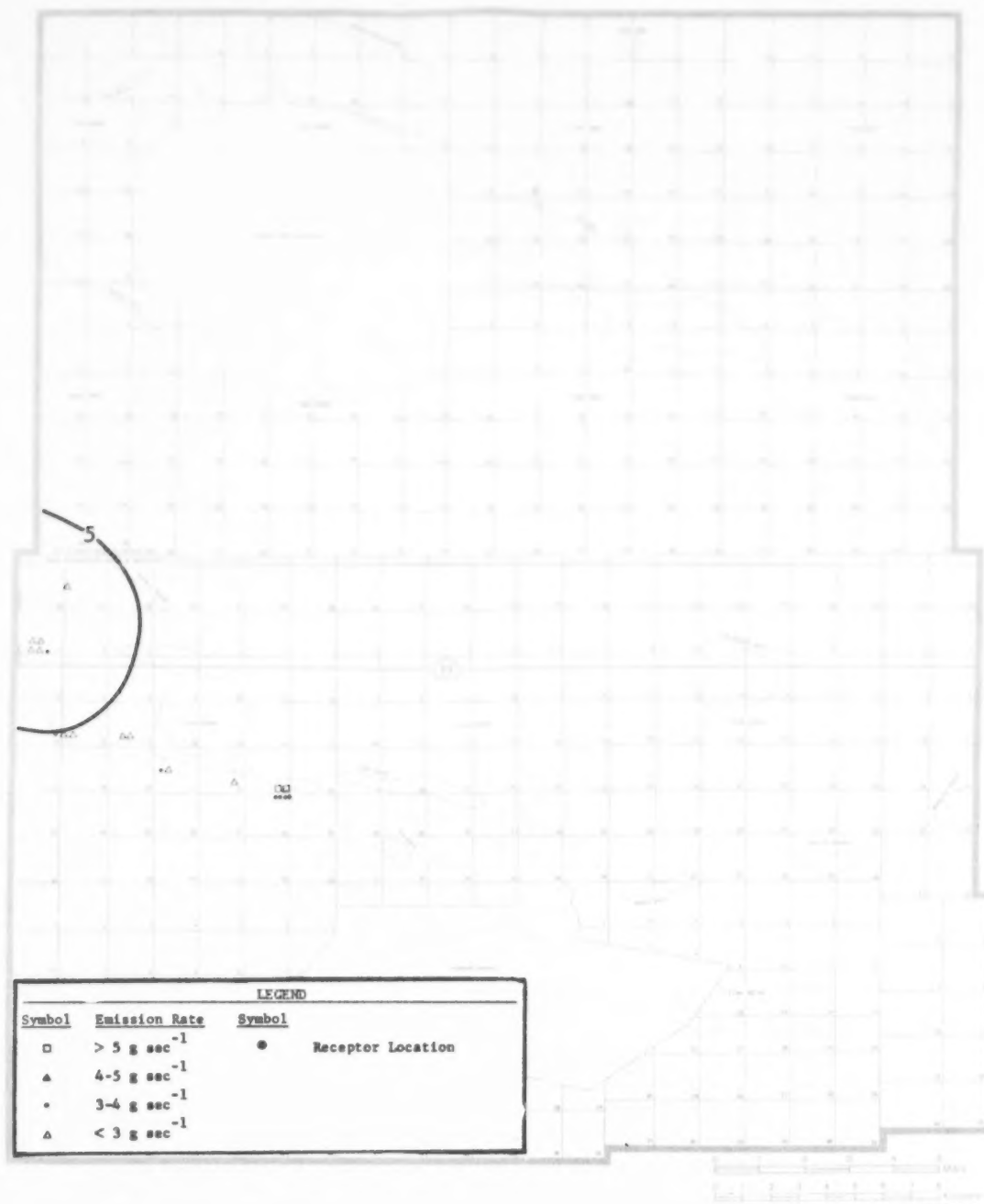


FIGURE 24 UNCALIBRATED ANNUAL AVERAGE SO₂ CONCENTRATIONS (ppb) IN SOUTHWESTERN KERN COUNTY (EXISTING SOURCES)

Based on the limited amount of air quality and meteorological data available, we conclude that the existing source configuration in western Kern County does not produce a sufficient amount of sulfur dioxide to exceed the annual SO_2 standard of 30 ppb.

C. Future Case Results

1. Central Kern County

To compute SO_2 concentrations resulting from the existing steam generators, those with permits pending, and proposed new generators in central Kern County, CDM was run with the future-case source inventory (listed in Appendix B) and the nongenerator source inventory. As for the existing case, the model was run with the original frequency distribution and the computed concentrations were calibrated. The uncalibrated concentrations appear in Figure 25, while the calibrated concentration pattern is illustrated in Figure 26. The maximum calculated value was 39 ppb; when calibrated, the maximum value was 23 ppb.

To produce the future case equivalent to Figure 18, the original frequency distribution was used for receptors that were not downwind of the bluff (outside of the box), while the altered-frequency distribution was used for those receptors downwind of the bluff (inside of the box). Figure 27 shows the resulting SO_2 patterns. The maximum calculated value was 39 ppb. The computed concentrations were calibrated using the two sets of calibration factors (one for inside of the box, the other for outside of it) discussed both in Section V-A-1 and in Section V-B-1, in which the existing case results are presented. The calibrated future case SO_2 concentrations computed by this method are illustrated in Figure 28. The maximum calibrated concentration is 31 ppb. The area in which concentrations in excess of 30 ppb are predicted to occur is very small, and considering the uncertainties involved in air quality modeling, it is difficult to emphatically assert that a violation of the federal primary annual average SO_2 standard would occur with the proposed future-source configuration.

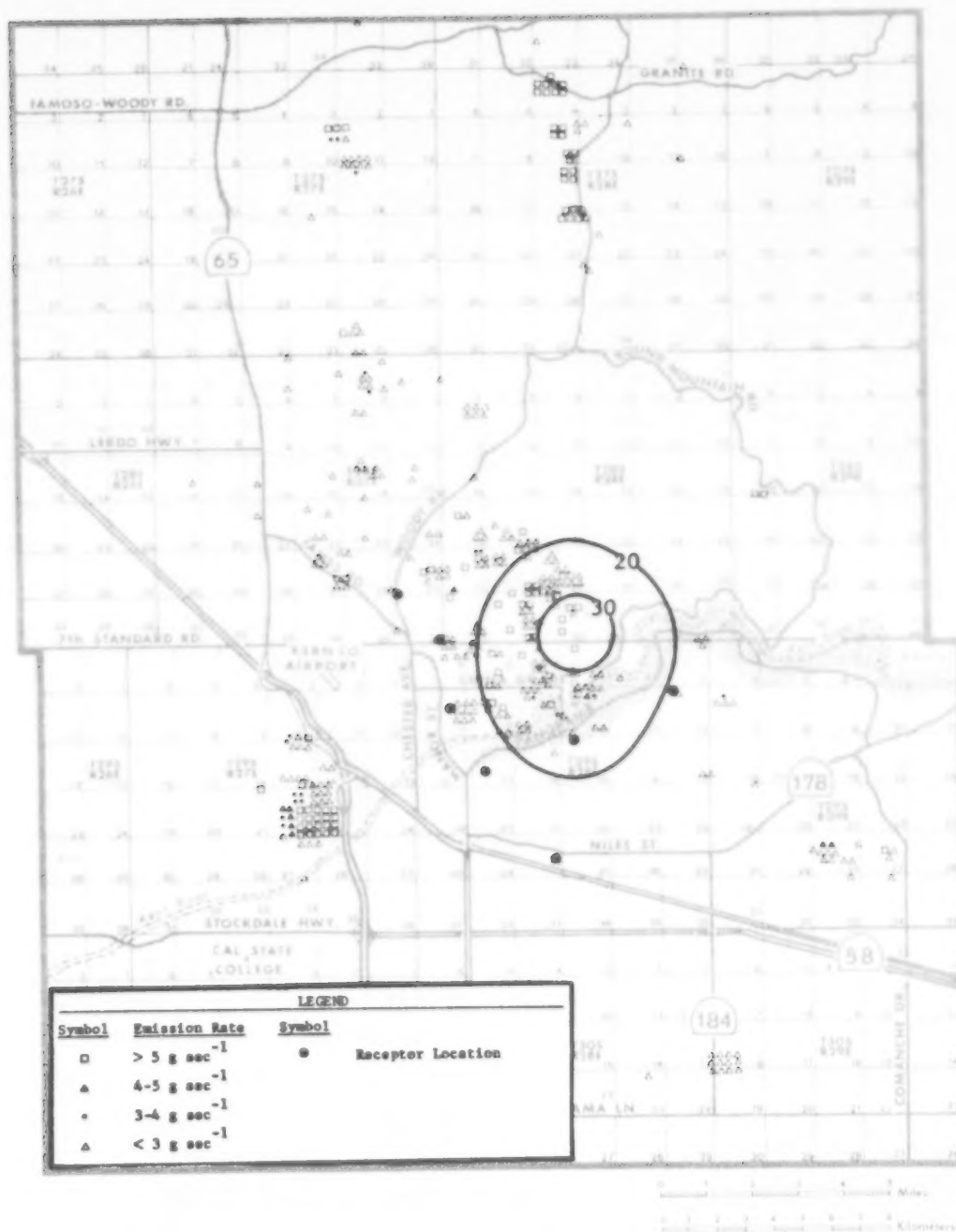


FIGURE 25 UNCALIBRATED ANNUAL AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE KERN RIVER OIL FIELDS (FUTURE SOURCES, ORIGINAL WIND FIELD)

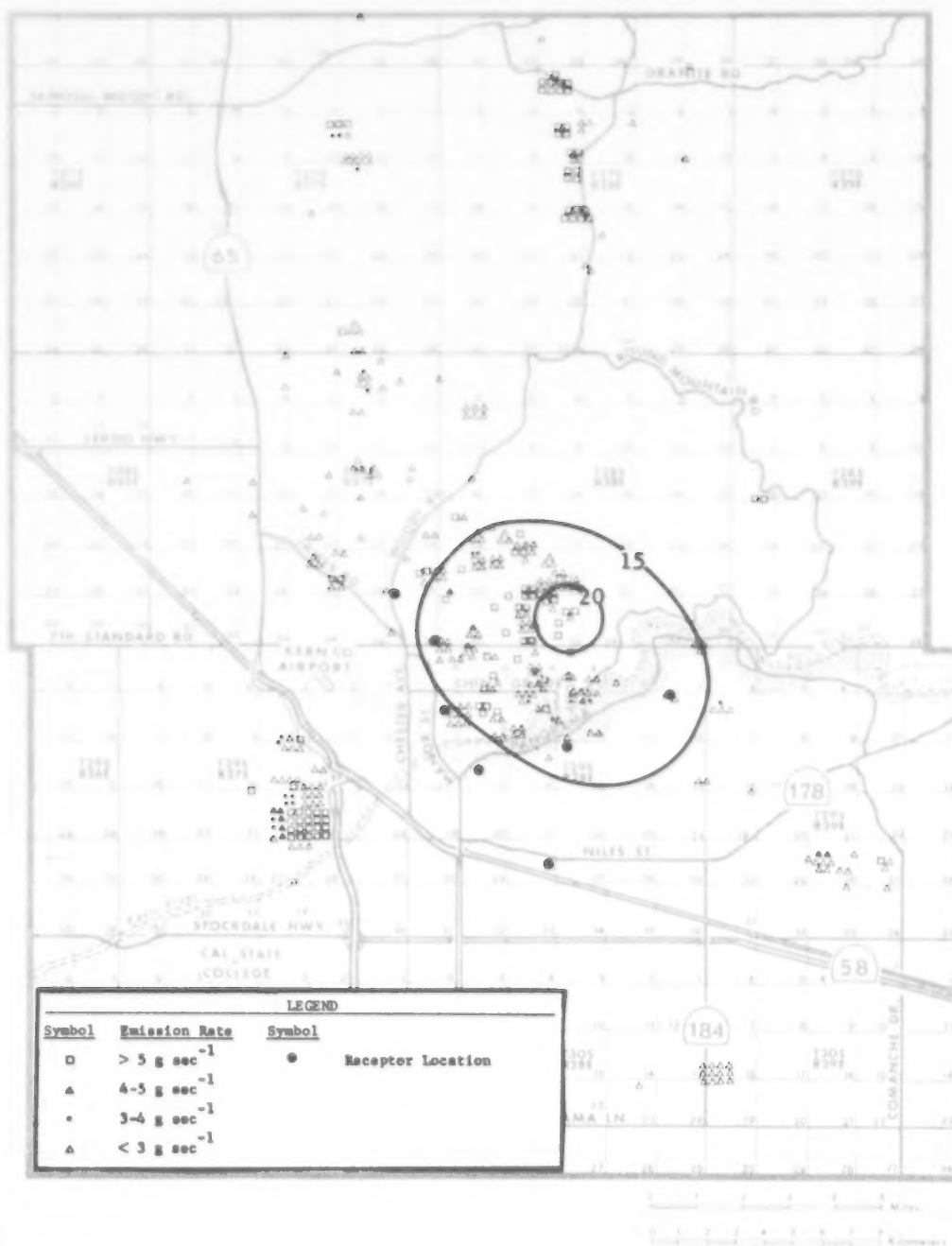


FIGURE 26 CALIBRATED ANNUAL AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE KERN RIVER OIL FIELDS (FUTURE SOURCES, ORIGINAL WIND FIELD)

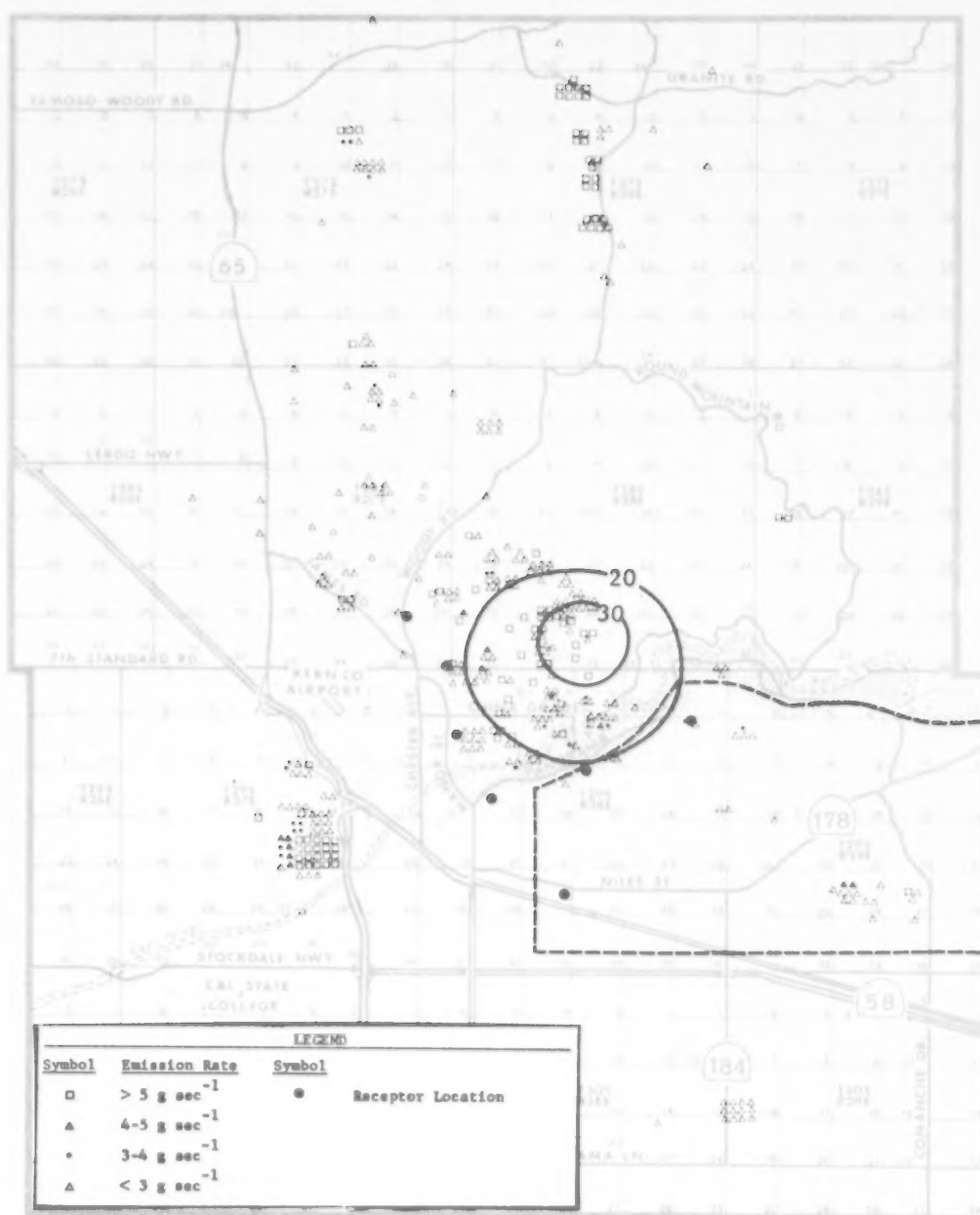


FIGURE 27 UNCALIBRATED ANNUAL AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE KERN RIVER OIL FIELDS (FUTURE SOURCES, ORIGINAL WIND FIELD OUTSIDE BOX, ALTERED WIND FIELD WITHIN BOX)

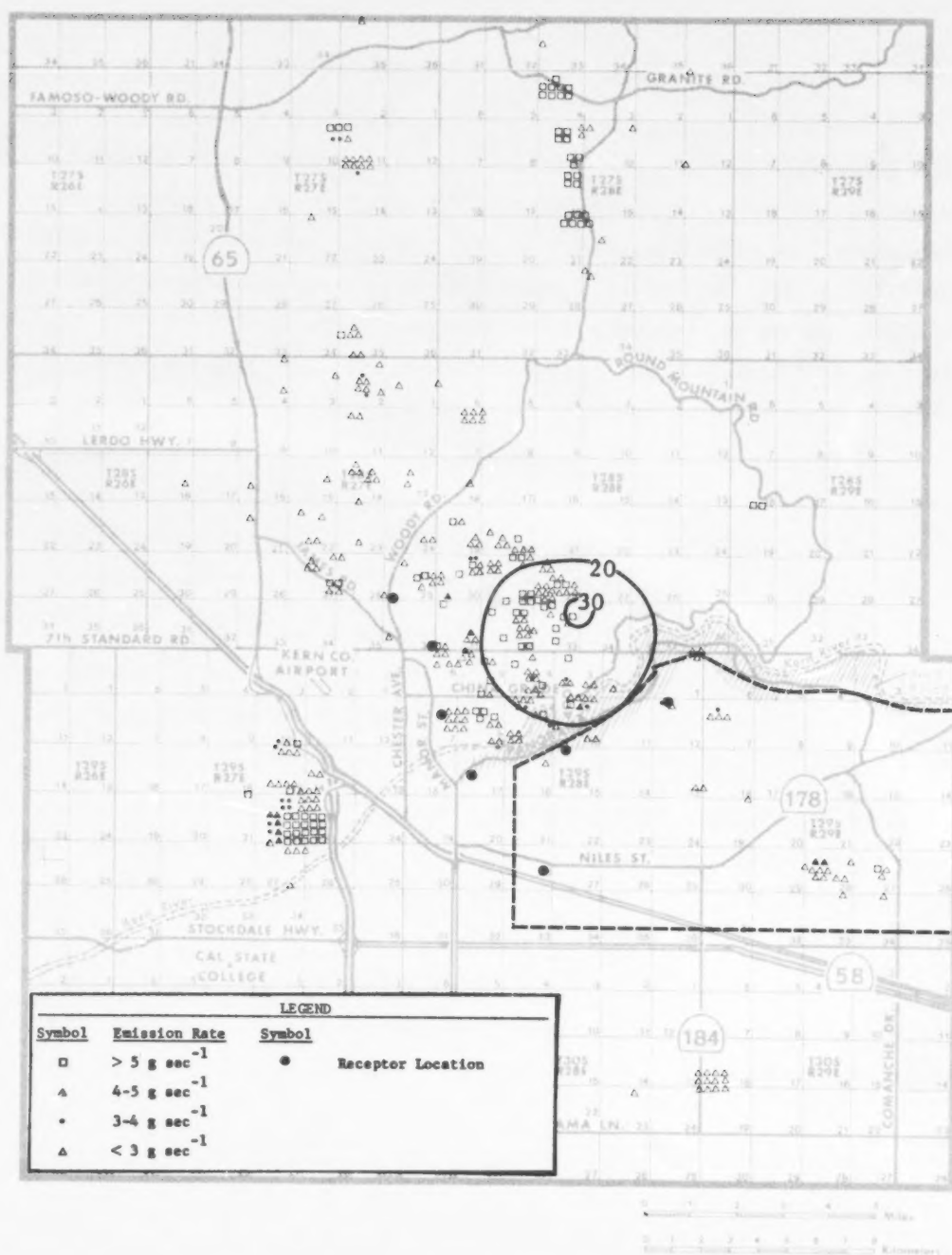


FIGURE 28 CALIBRATED ANNUAL AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE KERN RIVER OIL FIELDS (FUTURE SOURCES, ORIGINAL WIND FIELD OUTSIDE BOX, ALTERED WIND FIELD WITHIN BOX)

2. Western Kern County

SO₂ concentrations in western Kern County resulting from existing steam generation facilities, ones with permits pending, and proposed new facilities were computed with the CDM using the future-case source inventories listed in Appendix D (north sources) and Appendix F (south sources). As for the existing case, two meteorological frequency distributions were used in model calculations. Concentrations were computed according to the method outlined in Section V-B-2, in which existing case results were discussed.

Uncalibrated annual average SO₂ concentrations in the Belridge-McKittrick area are presented in Figure 29. After calibration, the concentration pattern is as shown in Figure 30. The maximum uncalibrated and calibrated concentrations were 27 ppb and 13 ppb, respectively.

Uncalibrated annual average SO₂ concentrations in the Fellows-Taft area are shown in Figure 31. Figure 32 gives the calibrated concentrations in that area. The maximum uncalibrated concentration calculated with CDM was 49 ppb; the maximum calibrated concentration was 24 ppb.

Finally, the uncalibrated annual average SO₂ concentrations in southwestern Kern County are shown in Figure 33. After calibration, all concentrations in this area are less than 5 ppb, as are all concentrations in western Kern County areas not shown.

As with the existing source configuration, the proposed future-source configuration does not appear to cause a violation of the 30 ppb annual SO₂ standard.

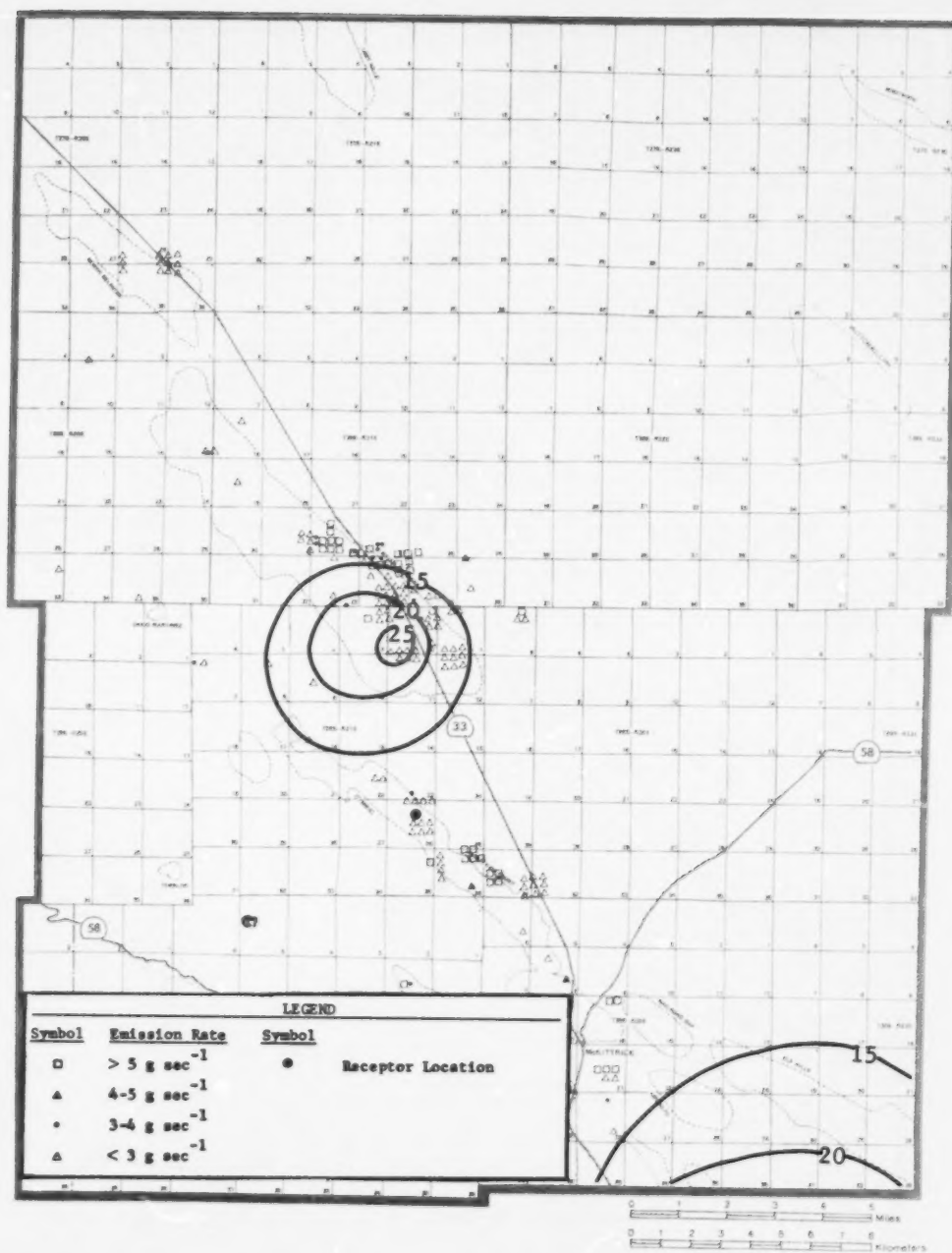


FIGURE 29 UNCALIBRATED ANNUAL AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE BELRIDGE-MCKITTRICK AREA (FUTURE SOURCES)

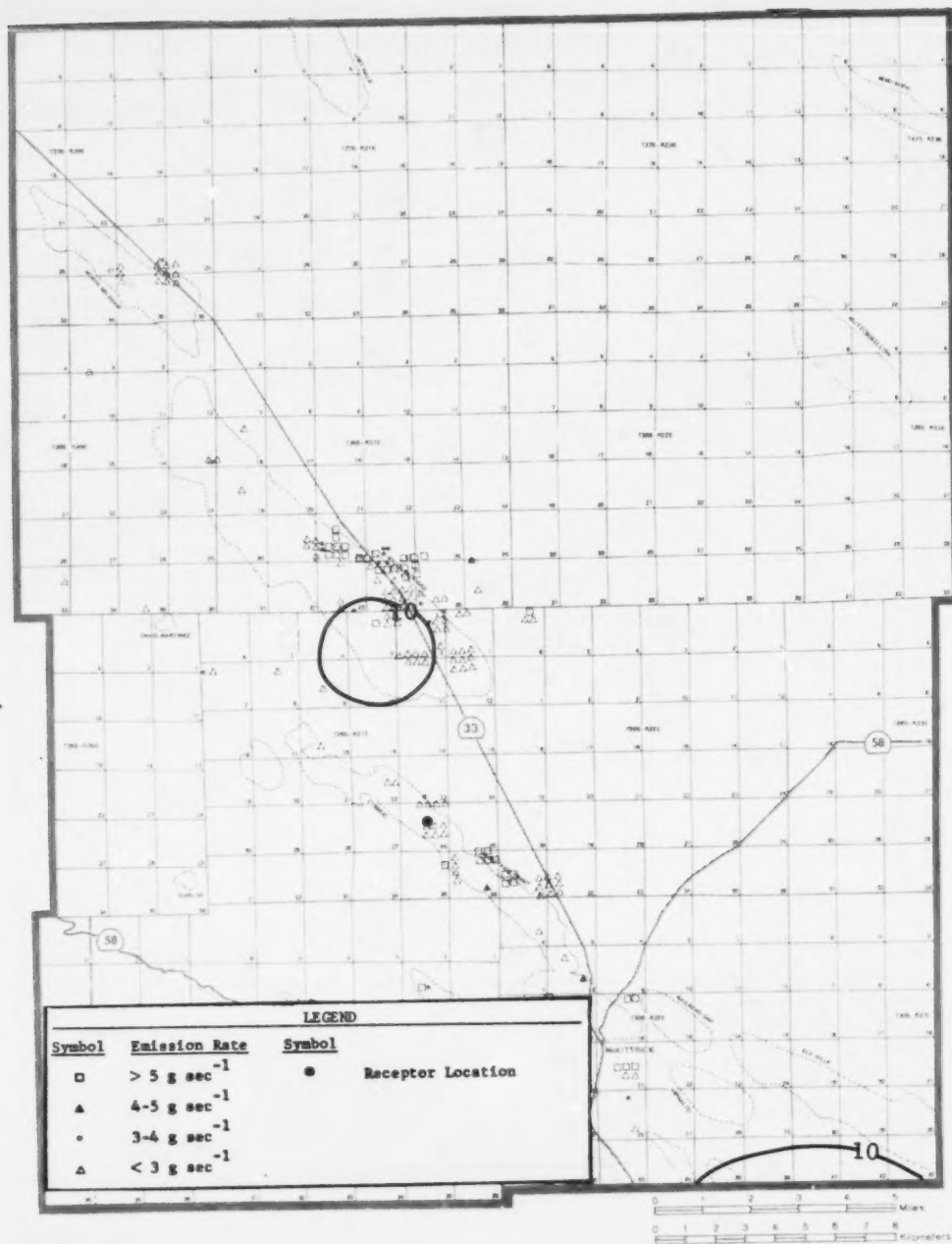


FIGURE 30 CALIBRATED ANNUAL AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE BELRIDGE-MCKITTRICK AREA (FUTURE SOURCES)

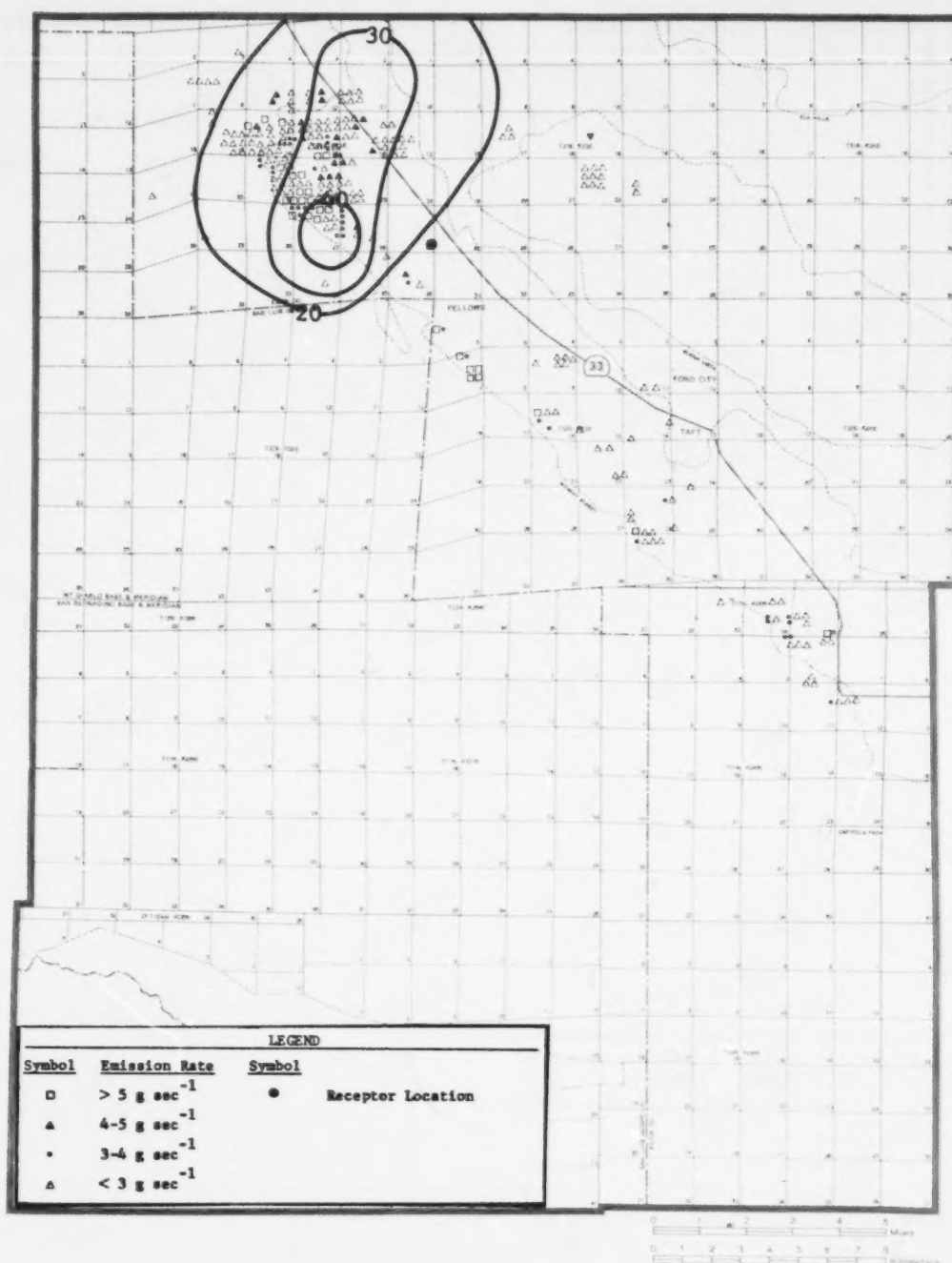


FIGURE 31 UNCALIBRATED ANNUAL AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE FELLOWS-TAFT AREA (FUTURE SOURCES)

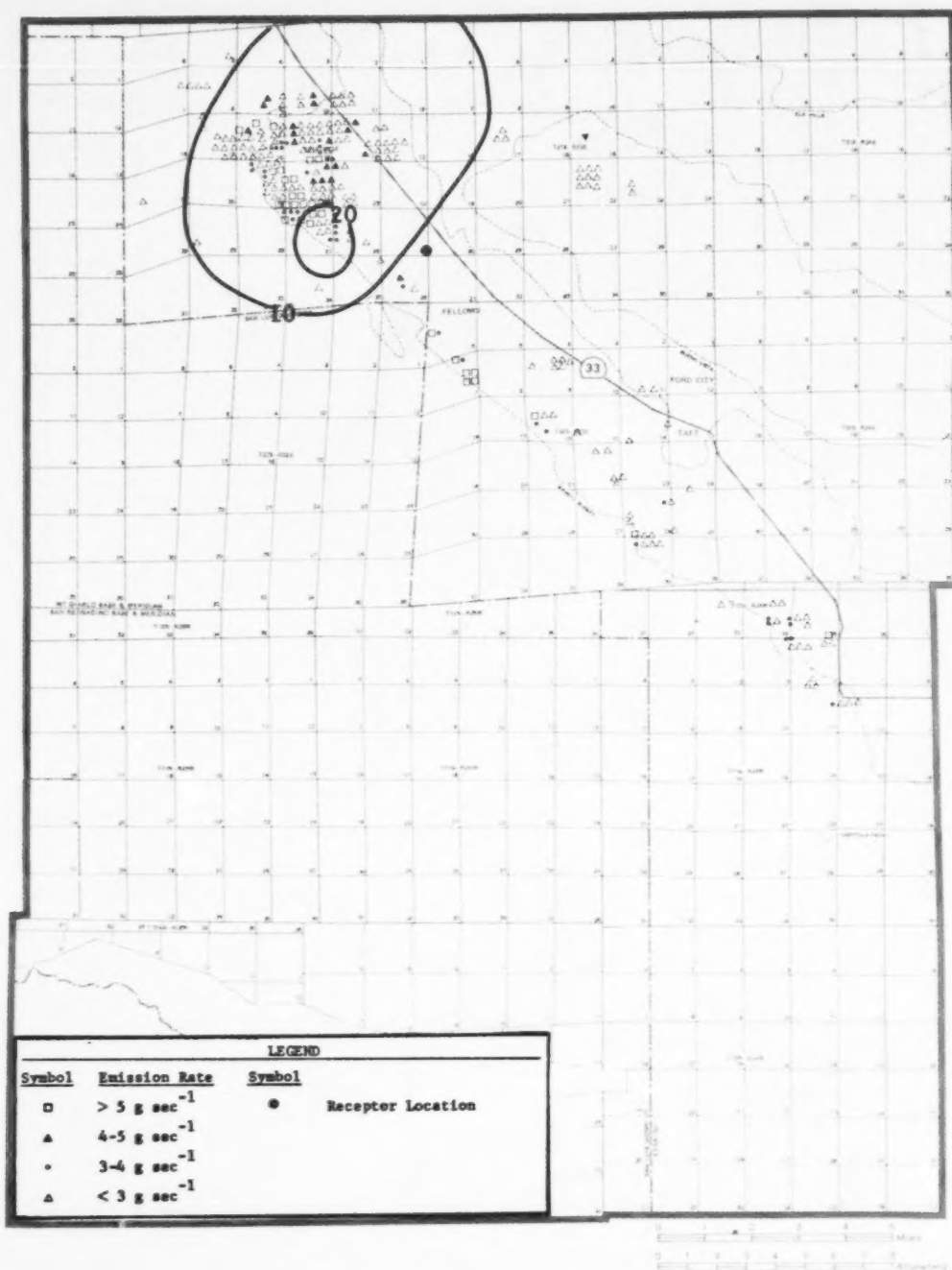


FIGURE 32 CALIBRATED ANNUAL AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE FELLOWS-TAFT AREA (FUTURE SOURCES)

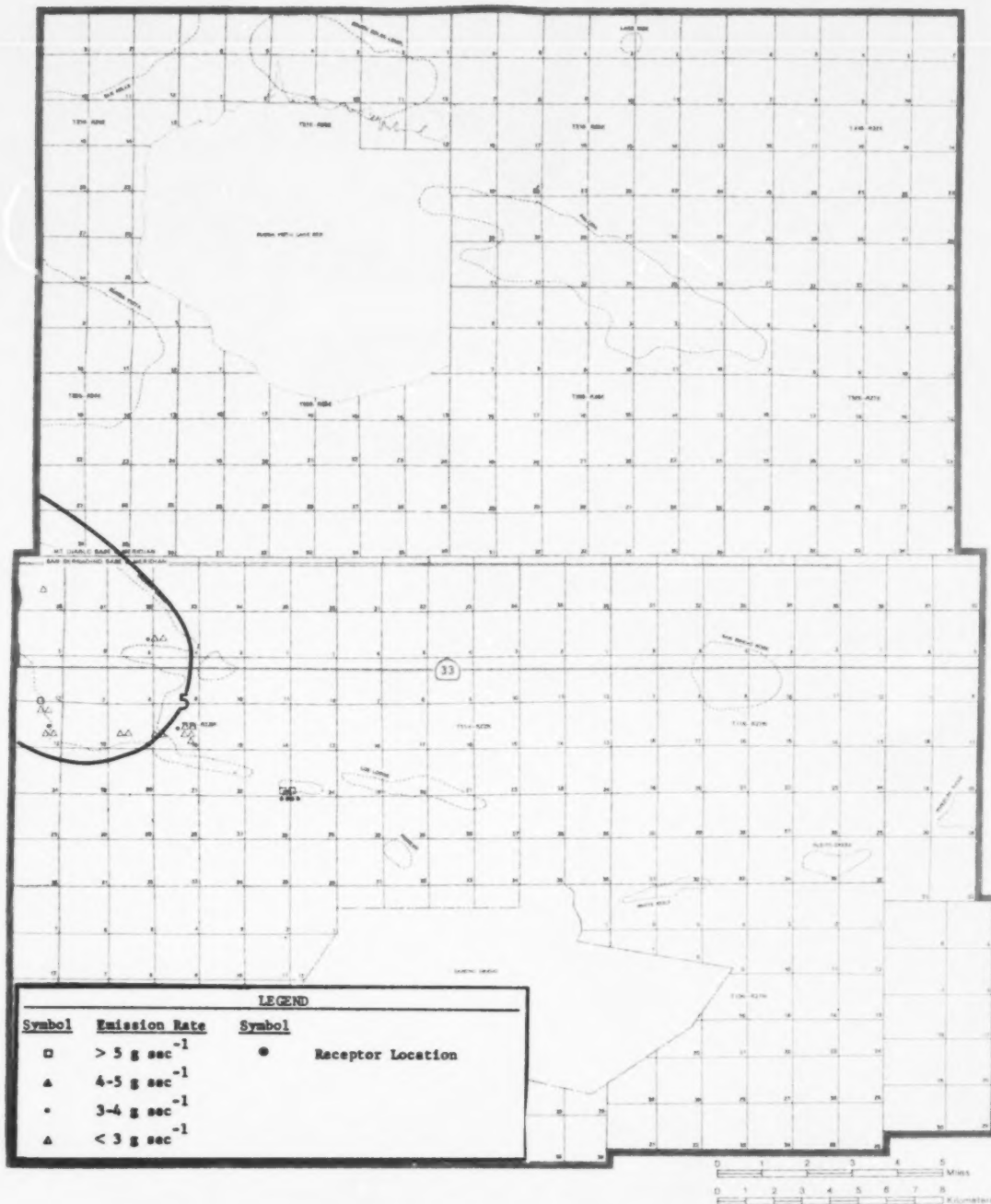


FIGURE 33 UNCALIBRATED ANNUAL AVERAGE SO₂ CONCENTRATIONS (ppb) IN
SOUTHWESTERN KERN COUNTY (FUTURE SOURCES)

VI MODELING OF SHORT-TERM AVERAGE CONCENTRATIONS

All of the SO_2 concentrations presented in this section have not been calibrated. Calibration of a steady-state model for a period as short as one to three hours is not recommended. In addition, the paucity of measurements made in Kern County and the mismatch of dates of some of the available data are further argument against any attempt to calibrate the concentrations computed for short-term averaging periods. Nevertheless, some one-hour averages were computed with CDM for comparison with measured concentration data. These computations were made more as a check on CDM's performance than as a means of establishing calibration criteria. The results of the computations indicated that CDM was suitable for computing short-term averages in this application, but that no calibration factors should be applied.

A. Existing Case Results

1. Central Kern County

The CDM model was used to compute the 1-hour, 3-hour, and 24-hour average SO_2 concentrations in central Kern County resulting from the existing SO_2 sources listed in Appendices A and G. Concentrations were computed for each of the two 24-hour meteorological scenarios listed in Table 11. Worst-case 24-hour average concentrations were found to result from the scenario in which the wind originated from 270 degrees for most of the day. The maximum computed concentration was 116 ppb; the existing-case concentration pattern is illustrated in Figure 34. Note that the concentrations are below the federal 24-hour standard. It was not possible to determine whether the California 24-hour standard has been violated because a simultaneous oxidant violation is required and assessment of oxidant violations was considered beyond the scope of this study.

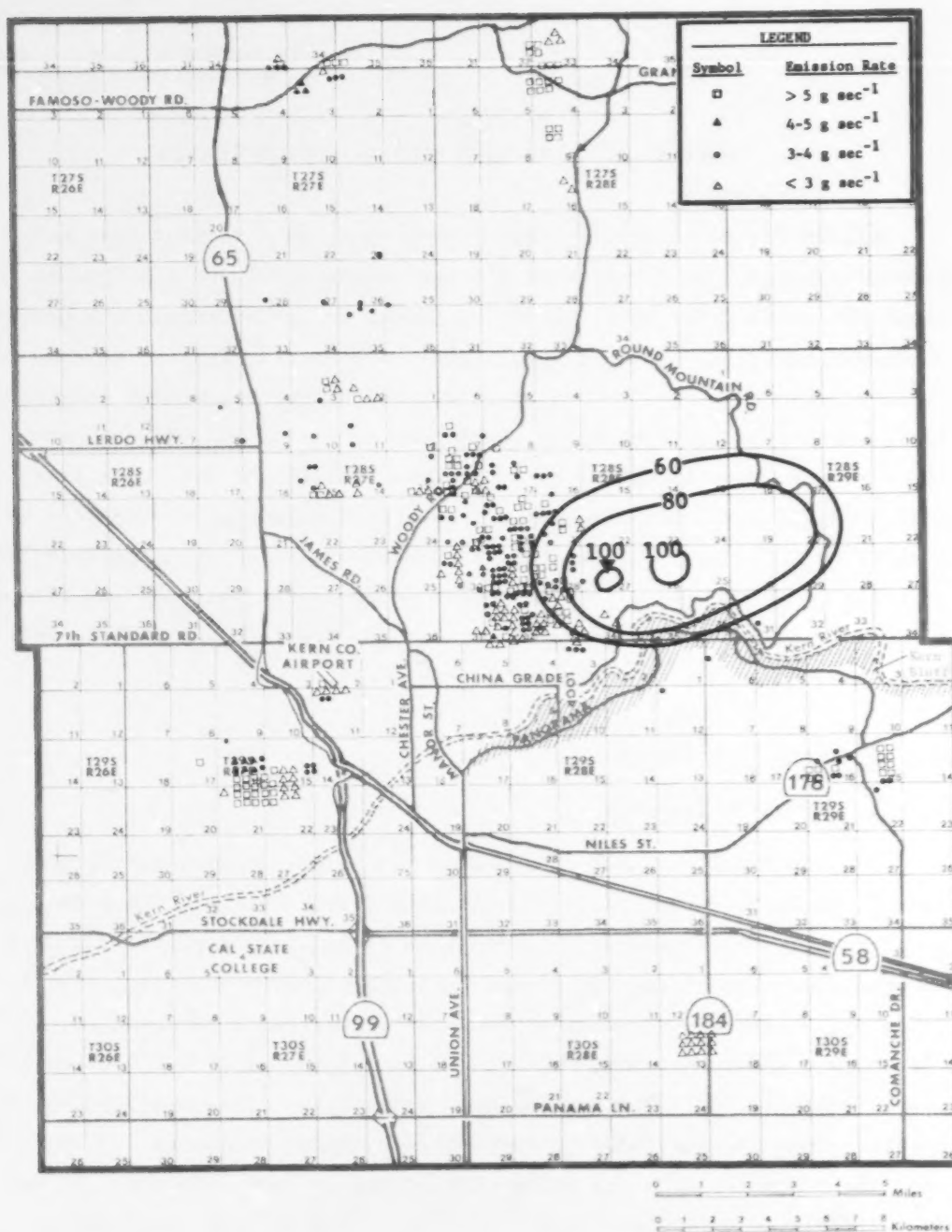


FIGURE 34 UNCALIBRATED WORST-CASE 24-HOUR AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE KERN RIVER OIL FIELDS (EXISTING SOURCES)

The worst-case 1-hour and 3-hour meteorological scenarios are identical, because the conservative assumption was made that the meteorology does not change in a 3-hour period. Of the six 3-hour or 1-hour scenarios listed in Table 11, the highest concentrations were found when the wind was from 157.5 degrees. The maximum computed concentration was 232 ppb--well below the 1-hour and 3-hour standards. Figure 35 shows the existing-case concentrations that occurred under the worst-case wind direction. Note here that concentrations computed for the 337.5 degree wind direction were of about the same magnitude as that for 167.5 degrees. However, the concentrations computed for the 337.5 degree wind are not presented because the presence of the bluff would probably influence the concentrations. Because of a lack of sufficient wind information, that influence on short-term concentrations cannot be assessed.

2. Western Kern County

Sulfur dioxide concentrations in western Kern County resulting from the existing source configuration, listed in Appendices C and E, were computed for worst-case 1-, 3-, and 24-hour averaging periods. The worst-case meteorological scenarios were assumed to apply to sources located in both the northern and southern portions of the area.

Concentrations were computed for the three different 24-hour scenarios shown in Table 12. The highest concentrations occurred under the 67.5 degree wind direction; the highest computed value was 105 ppb. The existing-case concentration patterns are shown in Figures 36 and 37 for the two western Kern County areas, Belridge-McKittrick and Fellows-Taft, in which the highest concentrations occurred. The federal 24-hour average SO_2 standard is not violated.

Sulfur dioxide levels were computed for all of the 3- and 1-hour worst-case meteorological conditions listed in Table 12. Both the worst 1-hour and 3-hour average concentrations were predicted under a 247.5 degree wind direction. The maximum computed concentration is 455 ppb; that value is below both the 1- and 3-hour standards. Figures 38 and 39 show the worst-case concentrations resulting from the existing source configuration.

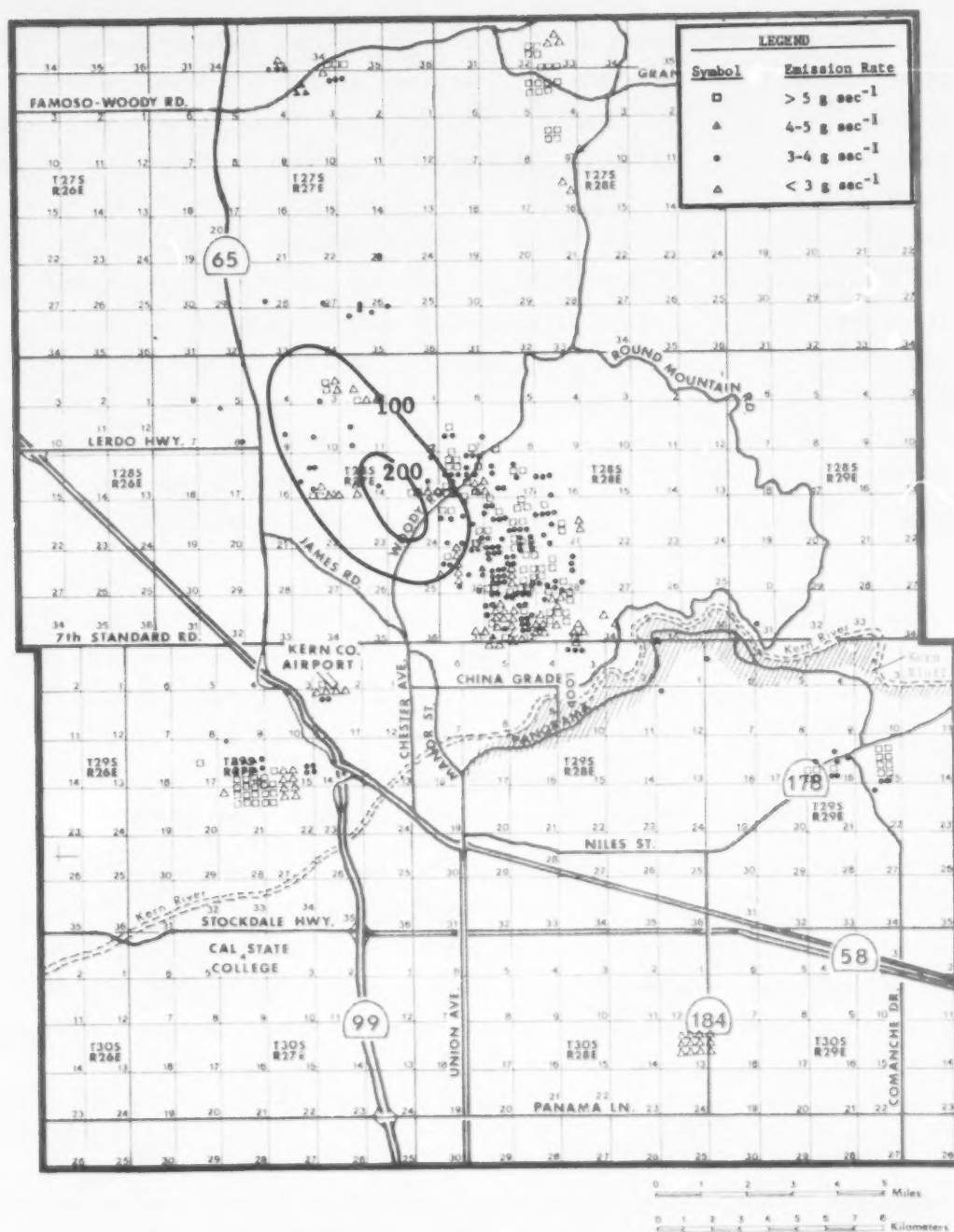


FIGURE 35 UNCALIBRATED WORST-CASE 3- OR 1-HOUR AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE KERN RIVER OIL FIELDS (EXISTING SOURCES)

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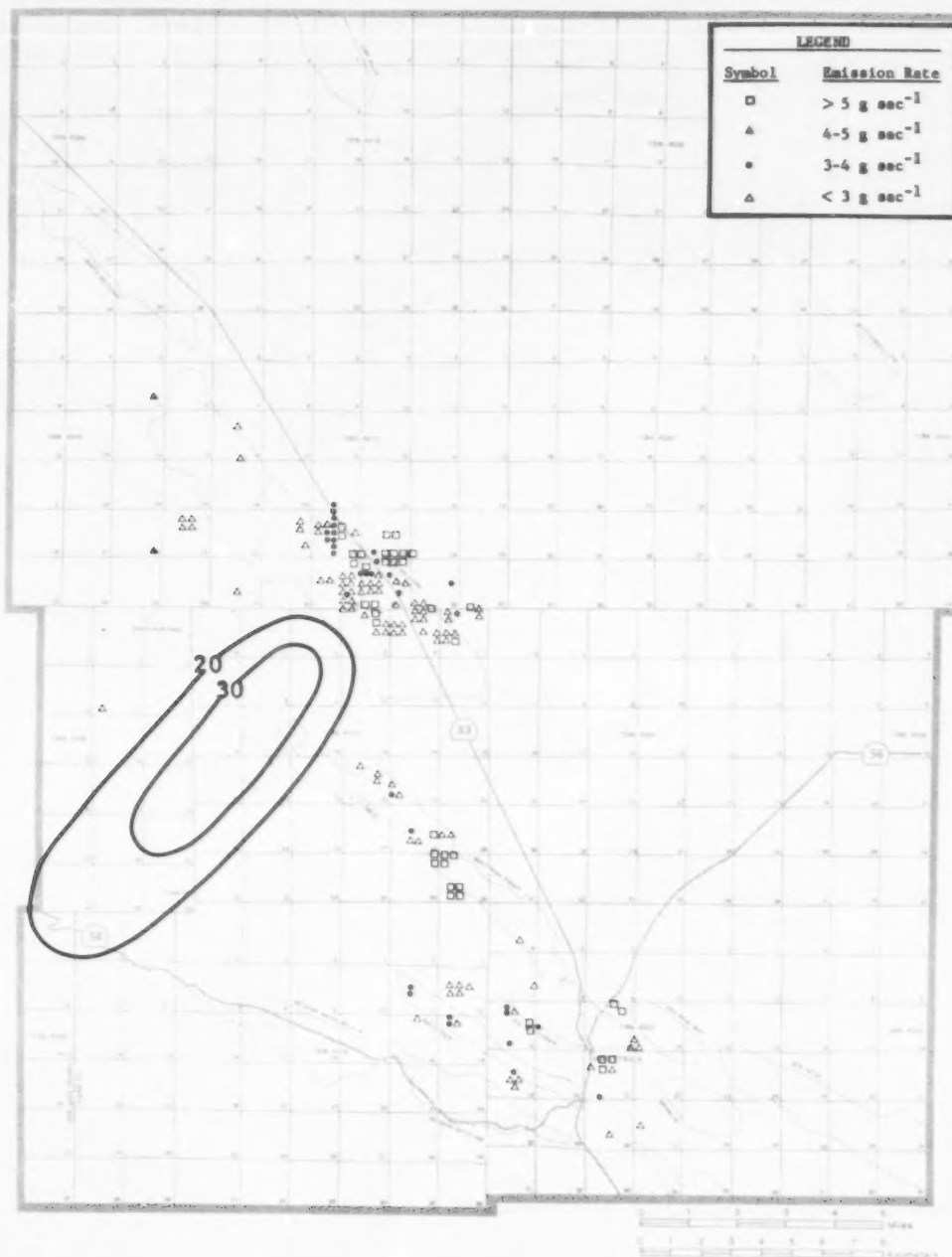


FIGURE 36 UNCALIBRATED WORST-CASE 24-HOUR AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE BELRIDGE-McKITTRICK AREA (EXISTING SOURCES)

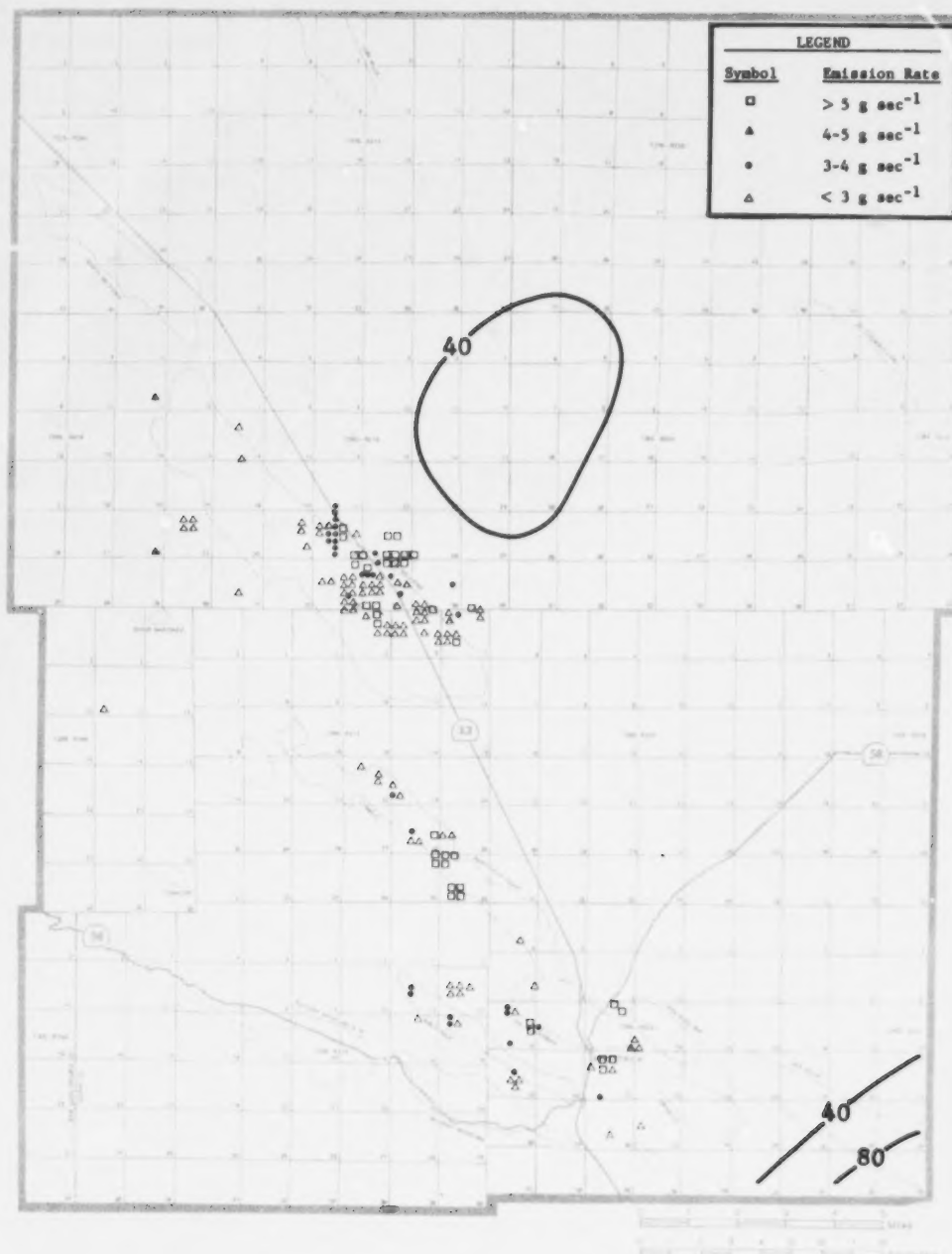


FIGURE 38 UNCALIBRATED WORST-CASE 3- OR 1-HOUR AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE BELRIDGE-McKITTRICK AREA (EXISTING SOURCES)

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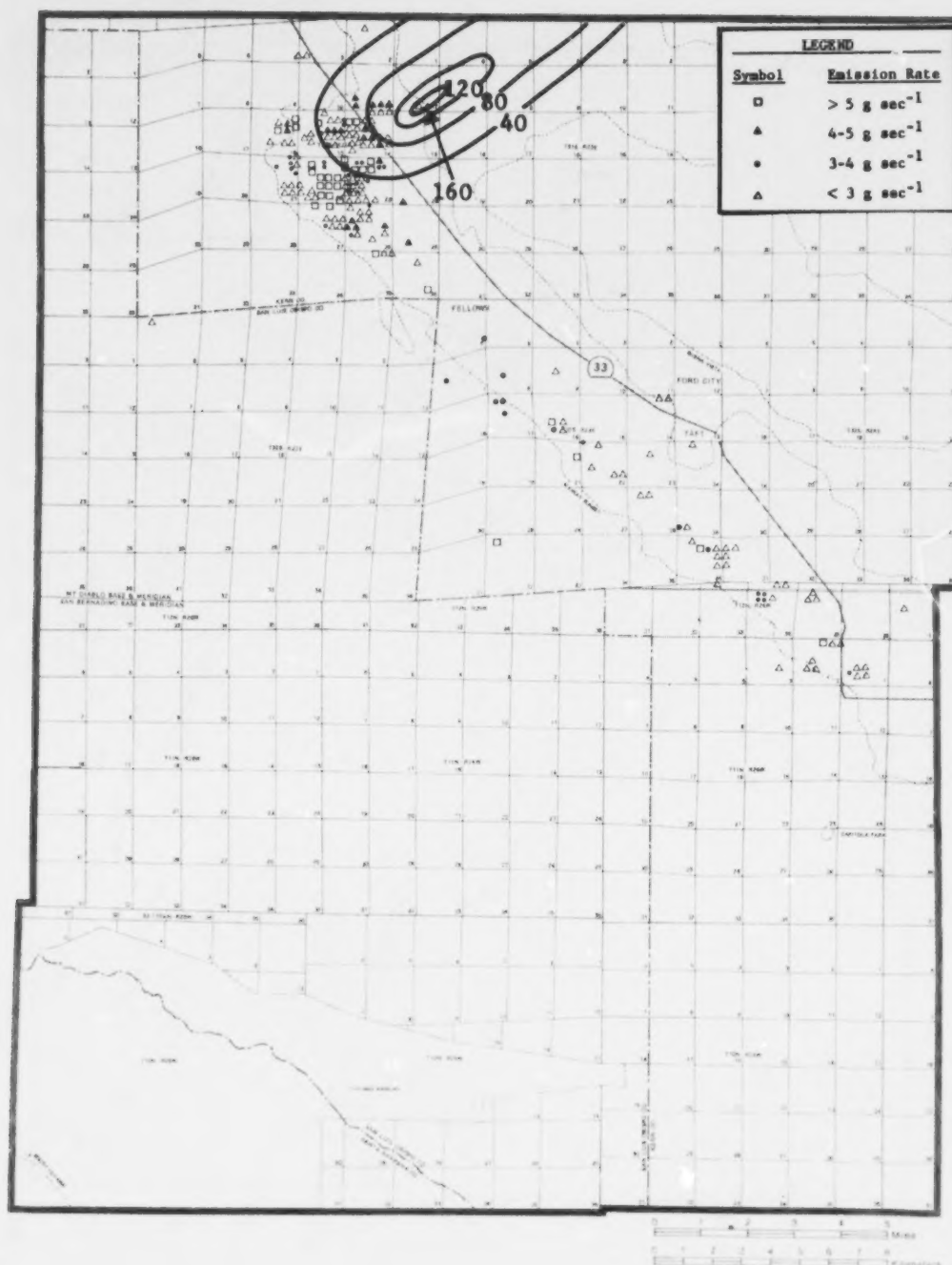


FIGURE 39 UNCALIBRATED WORST-CASE 3- OR 1-HOUR AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE FELLOWS-TAFT AREA (EXISTING SOURCES)

B. Future Case Results

The CDM was used to compute the worst-case 1-, 3-, and 24-hour average SO_2 concentrations resulting from the existing, permits pending, and proposed new generator sources in Kern County. Worst-case computations for each averaging period were made using the meteorological conditions determined to be worst-case for the existing inventory.

1. Central Kern County

Computations were made of the worst-case short-term SO_2 concentrations arising from the future-source configuration listed in Appendix B and from the nongenerator sources. The worst-case 24-hour average concentrations are illustrated in Figure 40. This pattern occurs under 24-hour meteorological scenario in Table 11 that is designated with an asterisk, where the wind is primarily from 270 degrees. The maximum 24-hour average concentration calculated was 71 ppb. No violation of the federal 24-hour standard is predicted.

The worst-case 1- or 3-hour average concentration pattern arising from the future-source configuration is shown in Figure 41. The wind direction was 157.5 degrees, and the maximum computed concentration was 91 ppb. Neither the 1-hour nor the 3-hour standard is violated.

2. Western Kern County

The 24-hour average worst-case SO_2 concentration arising from the future-source configuration (listed in Appendices D and F) appear in Figures 42 and 43. The wind was from 67.5 degrees, and the maximum computed concentration was 115 ppb. The federal 24-hour standard is not violated.

The worst-case 1- or 3-hour average SO_2 concentrations for the future case are shown in Figures 44 and 45, where the wind direction was from 247.5 degrees. The maximum computed value was 196 ppb, which does not violate either the 1- or the 3-hour standard.

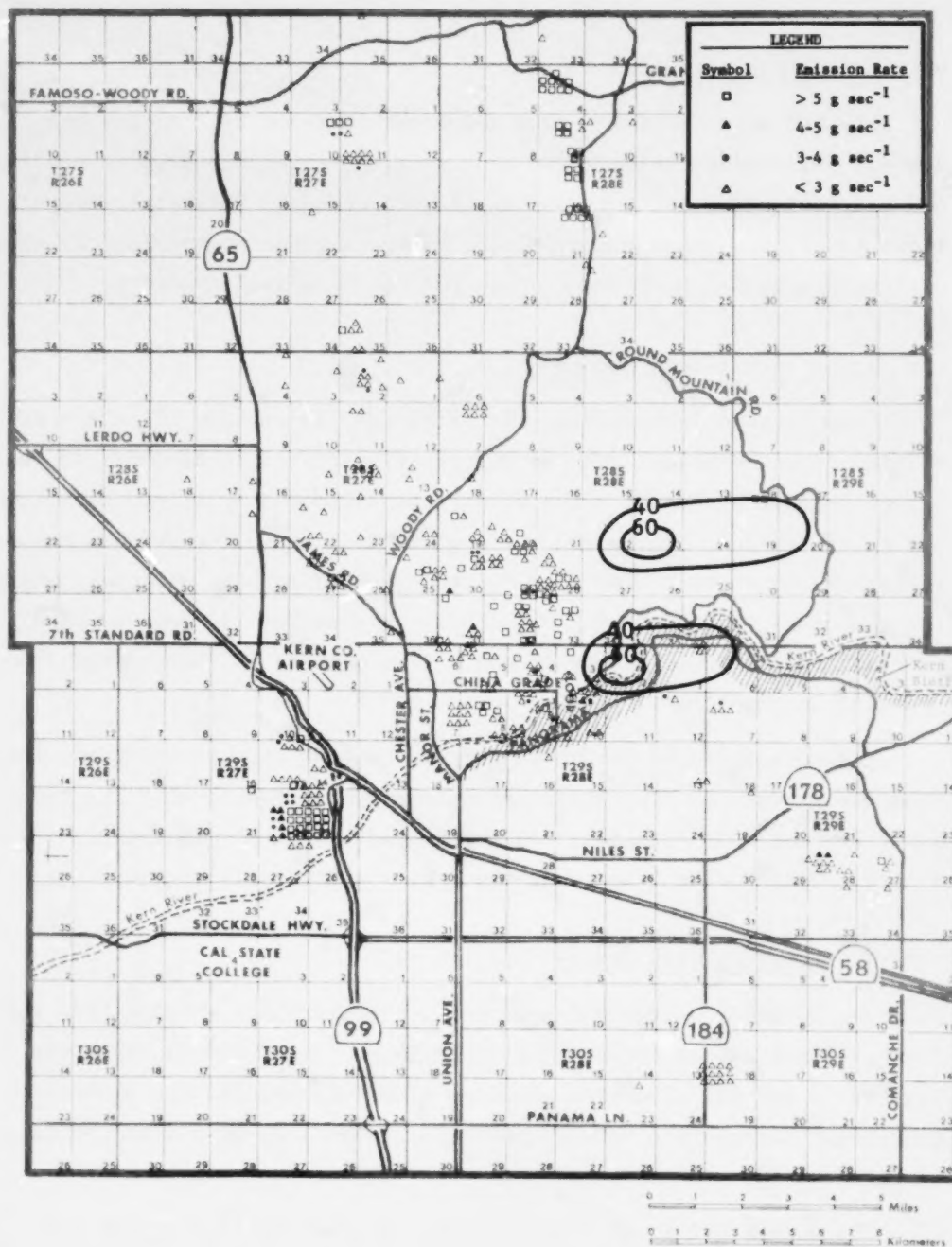


FIGURE 40 UNCALIBRATED WORST-CASE 24-HOUR AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE KERN RIVER OIL FIELDS (FUTURE SOURCES)

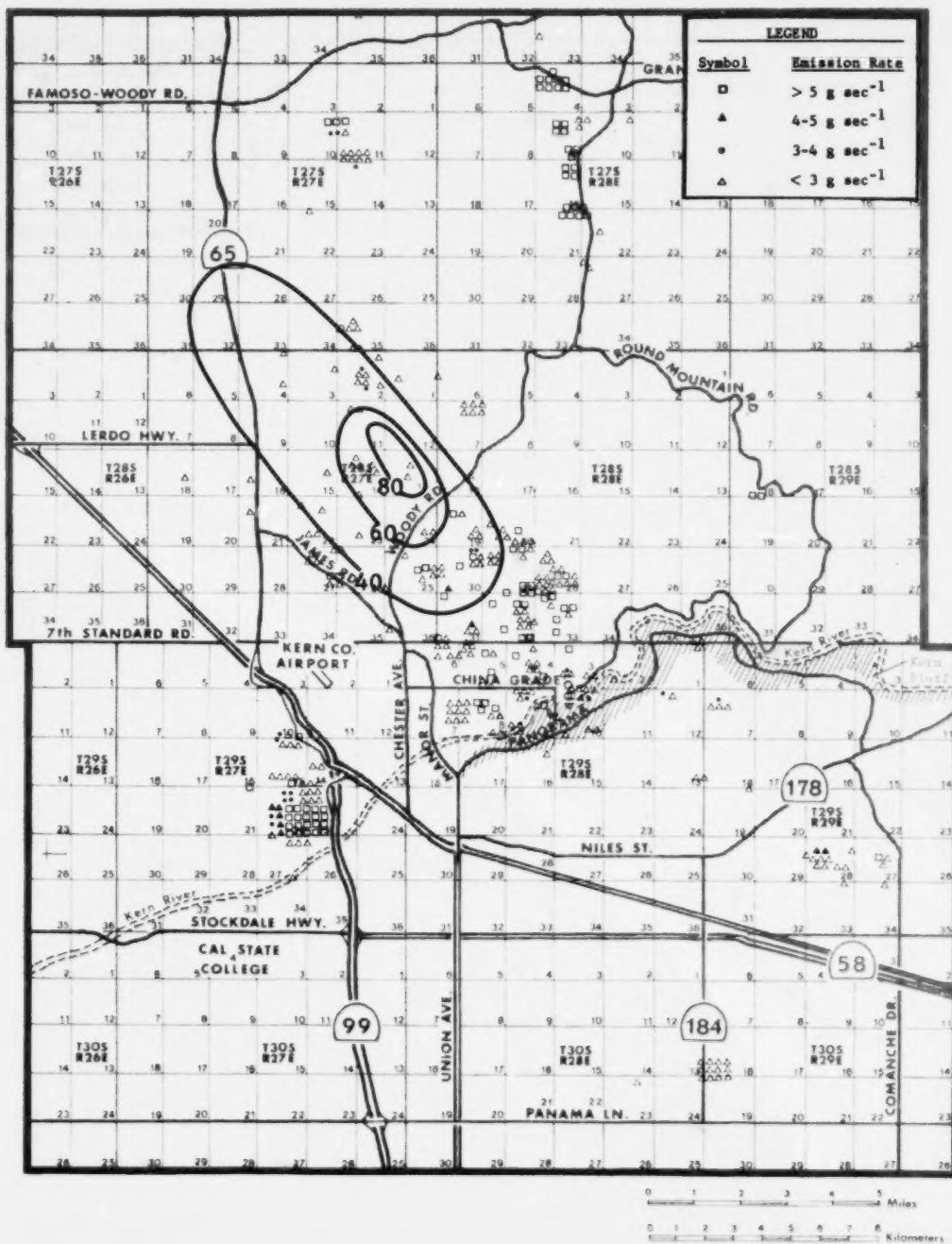


FIGURE 41 UNCALIBRATED WORST-CASE 3- OR 1-HOUR AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE KERN RIVER OIL FIELDS (FUTURE SOURCES)

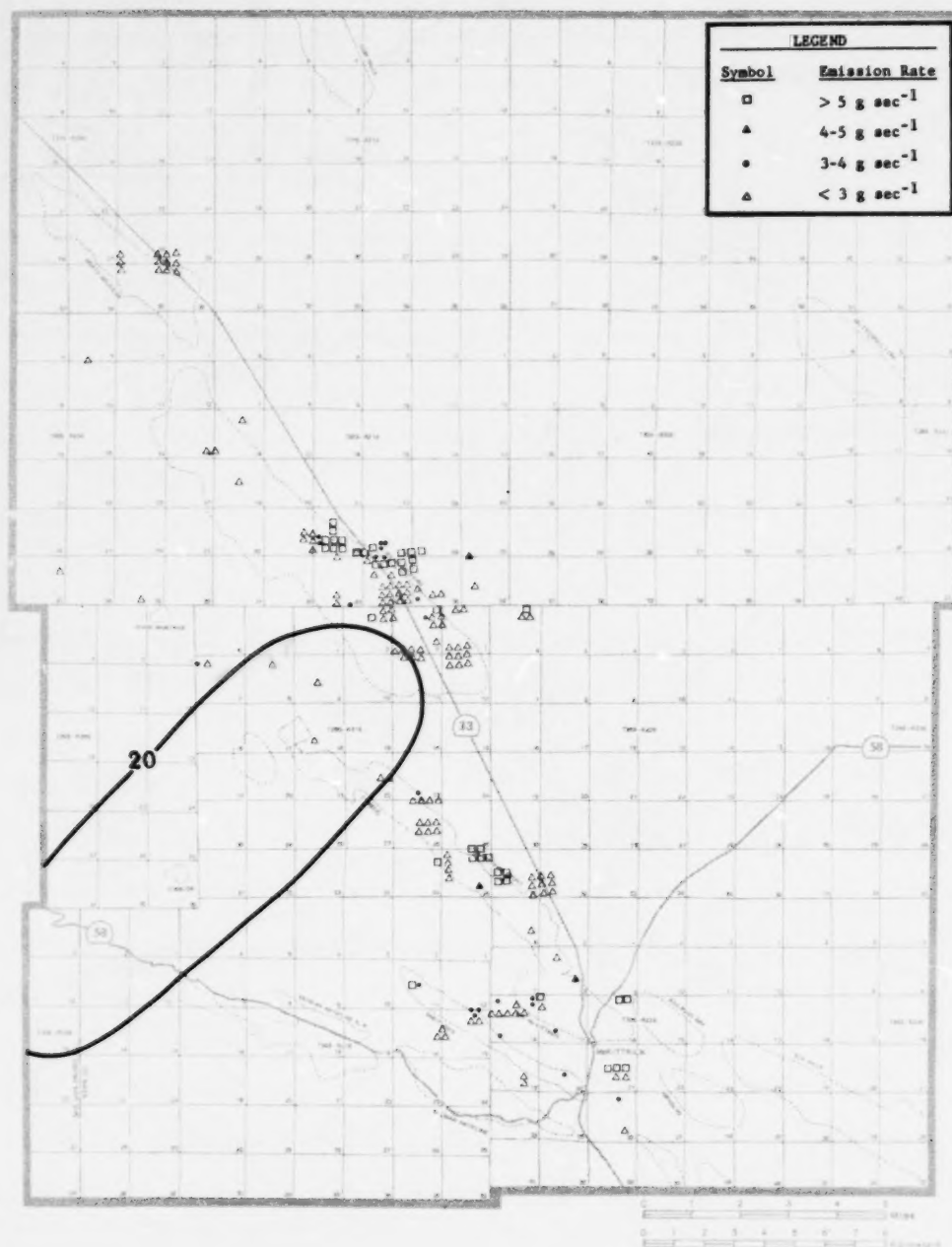


FIGURE 42 UNCALIBRATED WORST-CASE 24-HOUR AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE BELRIDGE-McKITTRICK AREA (FUTURE SOURCES)

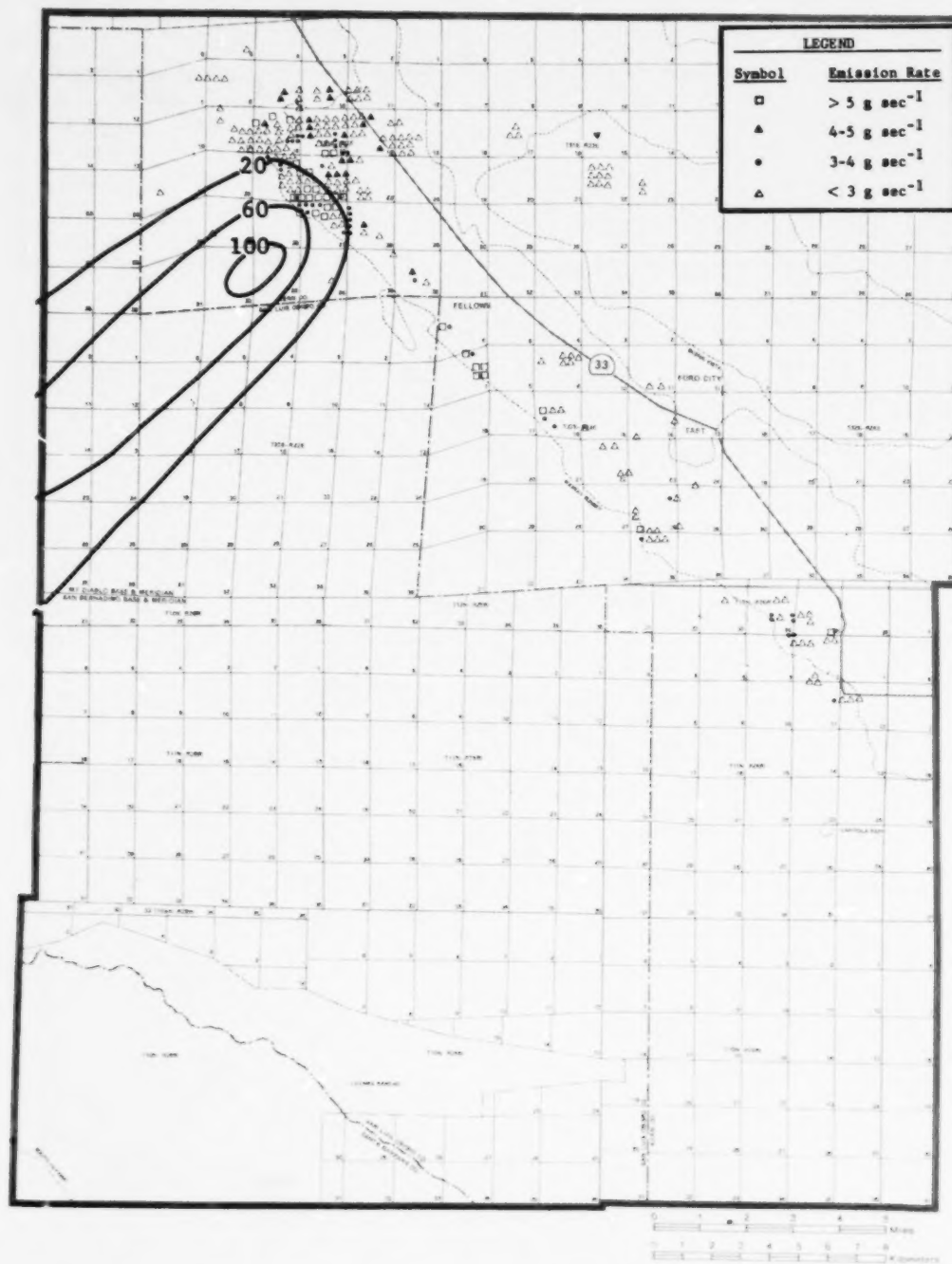


FIGURE 43 UNCALIBRATED WORST-CASE 24-HOUR AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE FELLOWS-TAFT AREA (FUTURE SOURCES)

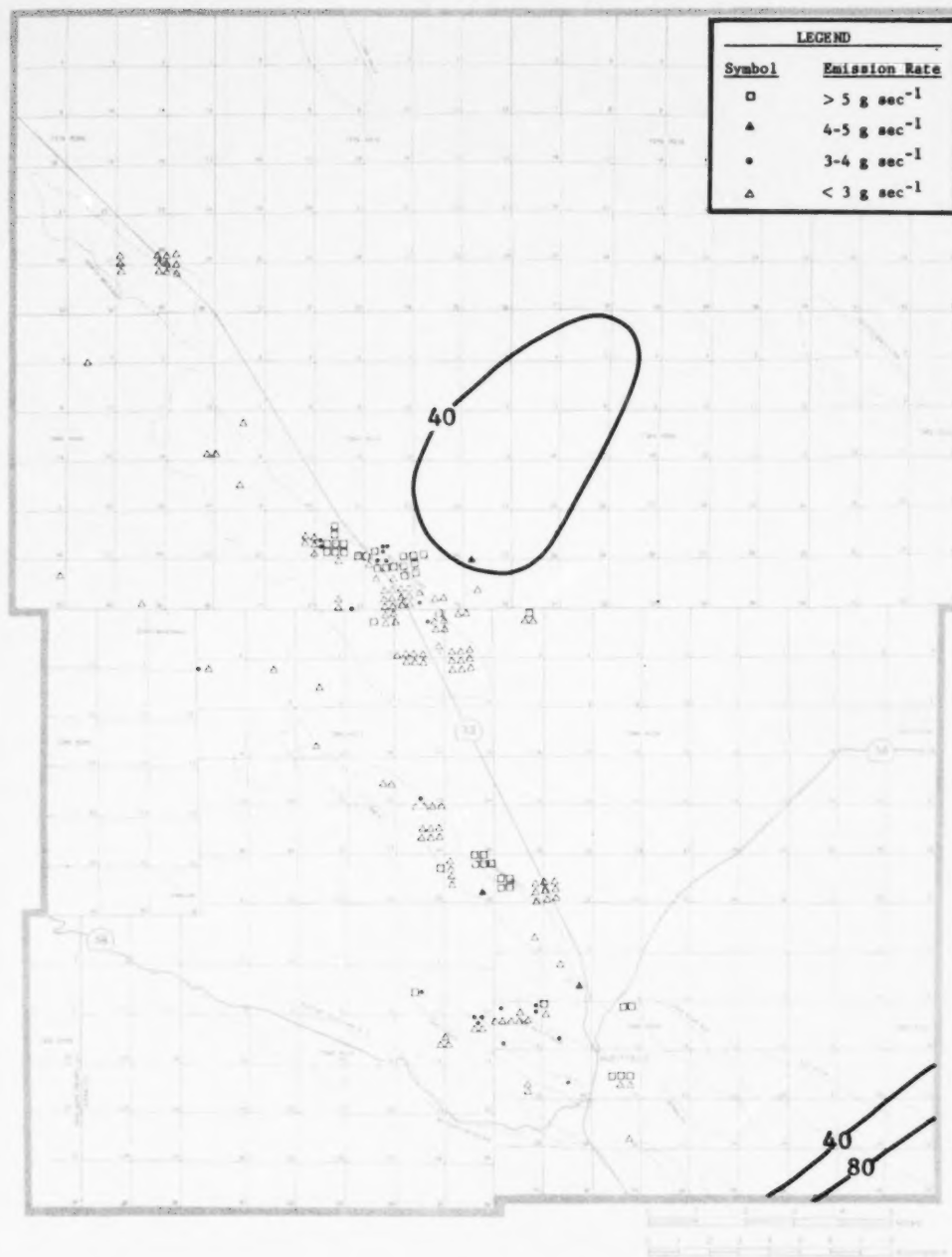


FIGURE 44 UNCALIBRATED WORST-CASE 3- OR 1-HOUR AVERAGE SO₂ CONCENTRATIONS (ppb) IN THE BELRIDGE-McKITTRICK AREA (FUTURE SOURCES)

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